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THE REARRANGEMENT OF RAILROAD TRACKS AND STATIONS IN COLOGNE, PRUSSIA.

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Cologne, the third city of Prussia in respect to population, has, inclusive of the suburbs, over 300 000 inhabitants.

In consequence of the demolition of the old fortifications in 1881, and the establishment of a new boundary about 500 m. (1 640 ft.) distant from the old one, Cologne has grown very rapidly in the last 10 years, the increase in population being about 60 000. Not merely its

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population, but also its extensive business interests and the commercial activity of its inhabitants, place Cologne at the head of the cities of the western provinces of Prussia.

The commerce of Cologne is partly that of the Rhine, about 500 000 tons per annum; but far more important is that of the railroads centering there.

Cologne is the terminus of three important railroad systems, viz.:

1. The lines on the right bank of the Rhine (to Holland, Hamburg, Berlin and the North).

2. The lines to Aix-la-Chapelle and Crefeld (to Belgium, Holland and England).

3. The lines to Bingen and Trier (the principal connection with the South).

The traffic of these lines was in the old arrangement provided for by two tracks through the main passenger station and by a few sidings. Since these tracks had no essential enlargement for 30 years they were inadequate to accommodate the increasing traffic. At present 82 passenger trains depart daily from the main passenger station, and 78 arrive; to these must be added many freight and other trains. The annual passenger business may be estimated at about 5 000 000 persons, of which 1 000 000 can be counted as of the city. Since almost all trains are made up in Cologne, and few pass through, the large through traffic must also be provided for, and it is astonishing that it was possible to do this so long in the old station in a systematic manner.

A second unfortunate condition of the old railroad tracks lay in the numerous grade crossings of streets. It was, of course, understood that in the new construction work these should be abolished or avoided.

Concerning the freight traffic the condition of things was similar, particularly because an extensive through traffic was controlled here. At the freight and switching station, Gereon, the switching reached the total annual amount of 1 000 000 cars, and in active seasons more than 4 000 cars were switched during 24 hours into their respective places. But this was the limit of possibility, while the traffic continually kept on increasing.

All these circumstances demanded an alteration of the layout, and

this indeed had been planned nearly 20 years ago by the former owners of the railroads, the Rhine Railroad Company and the Cologne and Minden Railroad Company. In consequence of the purchase of the lines by the Prussian Government in 1880, the opportunity for this rebuilding and improvement was materially hastened, so that in 1883 the necessary funds were voted by the Prussian House of Deputies.

I. The New Railroad System in General (Plate 1).

At the time when the preparation of the plans for the new system was begun, the demolition of the old fortifications, in order to extend the limits of the city, was in progress.

In consequence of this, the question arose whether the main passenger station should remain in its old location near the cathedral or should be transferred to the new part of the city. Several plans and estimates were made, but the final decision was in favor of the old location. To this condition and to that of the avoidance of grade crossings, by elevating the tracks above the streets, the entire plan was subordinated. There were many difficulties in carrying out the second condition, particularly with Eigelstein Street, back of the passenger station. This street had to be depressed about 2 m. (6.5 ft.), and the tracks were laid on the Rhine Bridge on a grade of 1 in 275, while the entire tracks of the station were laid on a grade of 1 in 400, in order to give the necessary heading of 4.65 m. (15.2 ft.) above the surface of Eigelstein Street.

On the other parts of the lines the steepest grade of the main track is 1 in 200, and the smallest radius is 300 m. (984 ft.).

Inside of the former city limits the old roadbed was utilized and widened, so that instead of the former double track three double tracks could be laid. One double track is devoted to the trains toward Bingen and Trier, another to those toward Aix-la-Chapelle and Crefeld, and between these are two tracks for the connection of the main station with the "traffic station" (Betriebsbahnhof).

At the traffic station the empty passenger cars are side-tracked and cleaned. There all the business in connection with fast freight traffic and with the through mails is conducted.

Hence, in the old city the railroad consists of six tracks which are supported by a viaduct or elevated substructure. Outside of the old

city, on account of the less value of land, earthen embankments are used for the roadbed.

The tracks of the Aix-la-Chapelle and Crefeld line soon leave the limits of the city and join the old line, while those of the Bingen line are laid close along the new ramparts until they join the old road.

On the last-mentioned line there are two passenger stations, West Cologne and South Cologne.

For the freight traffic there was erected a large freight and switching station, partly on the location of the old freight station. This is made accessible to the trains from and to Bingen and Trier by a branch connecting with the stations at West Cologne and South Cologne. For the lines toward Aix-la-Chapelle and Crefeld the freight tracks branch off near the ramparts at the point where the main tracks diverge to these two places. For the traffic on the right bank of the Rhine, a connection is made at Gladbacher Street near the passenger station, West Cologne.

To replace the old freight station, Pantaleon, a new freight station was erected at South Cologne, near the passenger station of that name. For the connection between the freight stations Gereon and South Cologne there is a special third track, which later will be extended to the improvements now in progress along the harbor.

II. The Main Passenger Station Near the Cathedral.*

(*a*) *Reception and Waiting Buildings* (Plates II, III, IV, V, VI).—The following fundamental conditions are established for the larger of the new passenger stations of the Prussian railroads:

1.—Passengers are not to be allowed to cross the tracks.

2.—The movement of baggage and mails to be on different platforms or passages from that of passengers.

3.—The distances traveled over in the station by passengers to be the shortest possible, regard being had to ascents and changes of direction.

The conditions 1 and 2 could be fully satisfied in the main passenger station in Cologne, but 3 could only so far as the relations of the surroundings allowed. In the train shed the tops of the rails are

* At the World's Columbian Exposition, in Chicago, the architectural plans for this passenger station have been placed on exhibition by the Prussian Minister of Public Works. Also a model of the large train shed is exhibited by the Union Company, of Dortmund.

about 4 m. (13.1 ft.) higher than the ground in front of the station itself. A prominent dome indicates to the passenger the door to the entrance hall. The dimensions of this, 41 by 18 m. (134 by 59 ft.), are such that, immediately on entering, the ticket offices are seen on both right and left. Moreover, on the right is a package-room, and on the left, rooms for the police and for the change of foreign money.

Directly beside the entrance hall to the left is the spacious baggage-room. The toilet-rooms for men and women lie between the entrance hall and the passage tunnel which leads under the tracks to Maximinen Street. The traveler passes half way through this tunnel, mounts a flight of steps and arrives at the waiting-rooms.

The waiting-room building contains on the main floor the waiting-room for first and second class passengers, and that for third and fourth class passengers; a dining-room situated between them; two ladies' rooms with a lavatory; rooms for royal passengers, and a few offices for employees (Plate III).

The kitchens and pantries for the restaurants are on an upper floor, while in the cellar underneath the waiting-rooms is space for storing provisions. On the main floor, beside the waiting-room of the first and second class passengers, is a buffet-room connected by a lift with the kitchen above. The cellar underneath the waiting-rooms is connected with Maximinen Street by a special tunnel.

For the passengers arriving from the west side of the Rhine a special exit tunnel has been provided underneath the tracks. At the end of this tunnel the traveler comes on the left to the baggage-room, and on the right to the package-room, toilets and lavatories. Moreover, near the baggage office are found some rooms for railroad officials, as also a hospital room for the reception of sick or wounded persons. In this northwest wing are found on the same level as the platforms two waiting-rooms for arriving passengers. The story above is reserved for the servants of the restaurant keeper.

For through passengers there are also two larger toilet-rooms at the end of the siding for the lines on the east of the Rhine.

At the extreme eastern end of the platforms, in the reception building, are the rooms for royal personages. The vestibule, which lies somewhat lower, is accessible by a few steps leading from the street. Between the rooms for royalty and the entrance hall rises the clock tower.

The baggage is carried from the baggage-room by means of barrows through special tunnels parallel to those used by passengers, and raised by hydraulic lifts to the baggage platforms. All these tunnels lead through to Maximinen Street; they are arched passages beneath the tracks, which later will in part be rented, but which will continue to be used by the ticket and baggage service until the reception building is completed. In these tunnels are also placed the dynamos for the electric lighting and the pumps for the hydraulic accumulators. The boiler house for these machines is located in Maximinen Street.

The front of the reception building is entirely constructed of Silesian sandstone.

All the roof structures of large span are built of iron. The ceilings of the entrance hall, baggage-room and exit hall are also supported by iron girders of different depths. These form rectangular panels which are filled with corrugated iron. The corrugations being in different directions in different panels, and the plates being partly arched, a striking ceiling pattern is formed.

The waiting-room building is built of iron-work with glazed brick and terra-cotta intermingled. In architectural comportment the rear of the reception building is also ornamented with glazed brick, while the roof is likewise of iron.

All floors are solidly formed by iron girders with béton arches turned between them.

The rooms of the entrance building and of the waiting building are heated by low-pressure steam; the boilers for this purpose are in an arched room underneath the tracks in Maximinen Street. In great part, however, the exhaust steam of the plant which drives the dynamos and pumps is utilized for heating.

(*b*) *Tracks and the Movement of Trains* (Plate III).—On each side of the long waiting building lie two main tracks, between which is an isolated platform 55 m. (180 ft.) in breadth. Two other pair of tracks terminate in this platform from each end, thus forming three projecting platforms. Further, there exist on both Maximinen Street and on the front means of exit. This arrangement was advantageous for Cologne, because nearly all trains are there made up. Each track has one platform for the passengers and another for the baggage and express. The tracks are spaced apart from 8.5 to 9.5 m. (27.8 to 31.1 ft.) when a baggage platform lies between, and about 12 m. (39.3 ft.)

when a passenger platform lies between. All the tracks are covered by a train shed.

The outside tracks, whose platforms are not directly connected with the middle one, are for freight trains, and for those local trains which are not used by passengers going far from the city. The switching connections are so arranged that each track can be used both for incoming and outgoing trains in many directions.

On both sides of the station are signal offices from which the signals and switches are operated. Each track has a signal for both outgoing and incoming trains, and the same is true for each of the main lines. Each signal office is under the charge of an official who has control of the departure and entrance of the trains. The two signal offices are nevertheless so far interdependent that the signals for the through trains on the main track can only be given by the common consent of both.

For the mails there is a special passage between the exit tunnels and Eigelstein Street which is connected with each baggage platform by a hydraulic lift. This tunnel passes under Marzellen Street and terminates at the main post office, so that the mail and express matter to and from Cologne is easily handled.

After the passengers and the mail for Cologne have been unloaded, the empty train, inclusive of postal and express cars, moves to the traffic station where the business of transferring through mail and express matter is done.

The lighting of the main passenger station is in general by electricity, but the offices are lighted by gas.

(c) *The Train Shed* (Plates VII, VIII and IX).—The train shed has a length of 255 m. (837 ft.) and a breadth of 92 m. (292 ft.), covering an area in round numbers of 22 200 sq. m. (238 970 sq. ft.). The following table gives a comparison with the other large train sheds of Europe:

Train Shed of Station.	Length. Feet.	Breadth. Feet.	Height. Feet.	Area covered. Square feet.
Frankfort-on-the-Main (3 train sheds)	600	184	93	336 340
Cologne	837	292	79	238 970
Bremen	430	194	89	83 620
Anhalt in Berlin	550	199	112	109 630
Midland, Manchester	563	210	....	118 210
Union, Glasgow	520	198	90	103 080
St. Pancras, London	705	243	100	171 260
Cannon Street, London	656	190	108	124 870

The cross-section of the train shed is formed by three spans, a middle span of 63.9 m. (209 ft.) and two side spans of 13.4 m. (44 ft.). The height of the middle part is 24 m. (79 ft.); this was made especially low on account of the proximity of the cathedral. The trusses of the central span are formed by arched girders in pairs, the two in each pair being 0.8 m. (2.5 ft.) apart, and united by both horizontal and diagonal braces. The ends of the arches are hinged on pins, and are supported on a narrow horizontal bedplate which is restrained from moving in a horizontal direction.

The single trusses are for the greatest part of their length built as lattice girders, but from the ends to a height of 2 m. (6.5 ft.) they have solid webs. The flanges have a T section, and to these the double diagonals are directly riveted. Upper and lower flanges are symmetrical. The distance apart of the trusses is 8.5 m. (27 ft.) from center to center. The roof covering is supported by iron purlins of a I or Z section, which rest on the upper flanges of the trusses. The connecting joints are so arranged that they transmit only vertical forces, the purlins being able to change in length under changes of temperature. This is effected by having at every other panel where the wind bracing is connected a continuous purlin with projecting ends to which the intermediate shorter purlins are joined by rivets in oval holes.

The wind bracing consists of round steel rods which carry the wind pressure on any truss to the masonry abutments.

The trusses support a spandrel structure on each side, the walls of which, 7 m. above the side spans, are glazed throughout their entire extent. To light the train shed more completely an upper construction 35 m. (115 ft.) wide extends over the whole length with the exception of the two end panels. This upper construction is formed by single small saddle roofs which extend at right angles to the length of the shed, and by a series of longitudinal window lights along the ridge. The side surfaces formed in raising these above the ridge form a ventilating *louvre*. For the same reason the covering above the trusses is slightly raised above the rest of the roof, so that side openings are formed where smoke and dust may have exit. In total, the openings for ventilation have an area of 1 600 sq. m. (17 200 ft.).

The ends of the train shed are enclosed by framing attached to the end trusses and have ornamented windows. The wind pressure acting upon these ends is transferred downward to a special girder.

The end trusses have a breadth of 4.1 m. (13.4 ft.), the others being only 0.8 m. (2.5 ft.). The end truss and the two trusses next to it are at both ends of the train shed, connected together by continuous purlins and by diagonal members, thus forming a rigid system, which is firmly connected for a length of 21 m. (68.8 ft.) to the end abutments, but which is allowed motion on the other four abutments under expansion from temperature.

The trusses of the side spans consist of arched girders, the lower chord of which is so elevated that the pressure line in the upper chord under uniformly distributed load has the same circular form as the chord itself. Against unsymmetrical loads these arches have a moment of resistance amply sufficient.

The roof covering is supported by Z beams. On the crown of each side span there is a longitudinal *louvre* which serves both for lighting and for ventilation. All the roof covering is corrugated iron.

The glass of the roof-lights has a thickness of 6 mm. (0.24 in.). The glass plates extend the entire width of the opening, the edges lying upon galvanized iron gutter plates, and are connected by screws passing through springs between them. In order to avoid stresses in the glass, pieces of felt are placed between it and the springs, and the felt is protected from dampness by being wrapped in tinfoil.

At each end of these upper windows in the direction of the length of the train shed is placed a ladder which, on one side of the building, is connected with steps leading downward.

The erection of the train shed was done under difficulties, since the work had to be carried on without disturbing the movement of trains and passengers on the tracks and platforms below. For an erection staging an iron structure 38.85 m. (127 ft.) in span was provided which had three trusses 5.5 m. (18 ft.) apart; these were firmly united by diagonal and lateral bracing. This staging was supported by 11 pair of wheels on a track on each side, so that it could easily be moved in the direction of the length of the building as the work advanced. The staging was so managed that it did not in any way hinder the temporary structures or the erection of the waiting-room building.

The movement of the staging, whose weight was about 140 tons, was effected very simply by 16 laborers with crowbars on each side, the time required to move it from one truss to the next, a distance of 8.5 m. (27 ft.), being from 45 to 60 minutes.

The total weight of the iron-work of the train shed, exclusive of corrugated iron, is about 3 130 tons (6 900 500 lbs.). This amounts to 160 kg. per square meter (32.8 lbs. per square foot) of floor area for the large span, and 90 kg. per square meter (18.40 lbs. per square foot) for the side spans, the latter including the iron-work of the side wall on Maximinen Street.

IV. The Passenger Stations at West Cologne and South Cologne.

The passenger stations at West Cologne and South Cologne, which lie on the main line to Bingen, are arranged in a similar way.

The station at West Cologne receives its traffic from that part of the city, at present not thickly populated, and from the large village Ehrenfeld.

The station at South Cologne replaces the old station Pantaleon, and already has a considerable business, since its location is favorable for the southern part of the city.

The streets adjacent to these stations have their surfaces about 5 m. (16.4 ft.) lower than the tracks. The passengers pass from the front of the station into the entrance hall on the same level, in which are found the ticket office, baggage-room and toilet arrangements. A flight of steps, 3 m. (9.8 ft.) in width, leads to the platform between the main tracks, which, for a distance of 400 m. (1 312 ft.), are spread 14 m. (46 ft.) apart for this purpose. At the south end of this platform is a small waiting-house, and at the other end of the train shed is a narrow office for the station-men. This platform and the tracks are covered by an arched train shed of 19.5 m. (63 ft.) span and 60 m. (197 ft.) length, the sides of which are formed of iron columns walled in between with brick.

V. The Traffic Station.

The traffic station lies at the junction of the lines to Aix-la-Chapelle and Bingen. Its principal use is for storing empty cars, and it is connected with the main station by two tracks. Besides the tracks for empty cars, the traffic station includes the following:

First.—A car shed for cleaning the empty cars.

Second.—A shed for free and customs fast freight.

Third.—The place for transferring the through mails.

Fourth.—A round-house for passenger locomotives.

The car shed is about 125 m. (410 ft.) long, and has four tracks placed 4.7 m. (15.4 ft.) apart upon which cars are stored and cleaned. The walls are formed of iron bracings.

The freight shed has one part for free and another for customs freight. That for the free, or non-dutiable, freight has unloading scaffolds shaped like saw teeth in plan, so that on each diagonal face three cars can be handled. In front of the shed are four such scaffolds or platforms; moreover, in the rear of the shed are several others roofed over. By this arrangement the cars by the side of any given scaffold can be easily and quickly taken away by a locomotive without disturbing the other cars in front of the shed. This arrangement has proved to be an excellent one. The shed itself is built of wood; all the saw-tooth-shaped scaffolds are covered by the projecting roof. The neighboring shed for fast freight matter is accessible by a turn-table. At the end of this structure is an office building for those who have the conduct of this business.

The ground around the freight shed is connected with the neighboring streets of the city by an approach having a grade of 1 in 30.

The location for the handling of the mails is connected with the traffic station by a bridge over the west-bound freight tracks. The arriving postal cars are run upon a track over this bridge from which they are brought to the special platforms where the mail matter is transferred into different cars for different directions.

The locomotive round-house has room for 36 locomotives, and is reached by two turn-tables. The rear semi-circular wall is of brick, while the front columns, the doors and the roof consist of iron. The supplies of coal for the passenger locomotives are brought by small coal cars (so-called "dogs") which are lifted up by a crane and dumped into the tender.

VI. The Freight and Switching Station Gereon.

(*a*) *The Freight Yards.*—The Station Gereon serves in part for the through and in part for the local traffic, but the former is by far the more extensive.

About 70 freight trains arrive and depart every day. Almost all arriving trains must be made up again, and hence much switching is necessary.

The main freight line, which departs toward the north and west

after traveling out from the south-bound line, divides the Station Gereon into two parts. This is not a good solution of the problem, but it was demanded by the local circumstances.

In consequence of this division of the freight station, it was thought best to use the tracks south of the main line for the trains toward Aix-la-Chapelle and for the local traffic, and those lying north of the main line for the trains toward the south and for the traffic on the right bank of the Rhine. Thus the trains when made up can move from their sidings without crossing the main tracks.

Moreover, on the north side of the main tracks there is another track for cars for South Cologne, the harbor and other local points.

The tracks for departing trains are laid opposite to the west station. For trains toward Bingen and Trier there are three tracks, and for those toward Aix-la-Chapelle and Deutz there are two tracks alongside the main line. Moreover, there is a special track provided for trains leaving for Deutz. In general, arriving freight trains use the same tracks as those leaving.

At the front end of the tracks for departing trains there is an elevation of 0.5 m. (1.64 ft.), which is reached by a 1% grade in 50 m. distance, the grade on the other side being 2 per cent. This elevation is necessary in order that the cars may be easily uncoupled. The cars are not pushed off with a shock, but the train is brought into uniform velocity, and the cars move off in a corresponding manner. The velocity with which a train can be thus broken up depends upon the intervals in which the cars are detached. This interval must be so large that two cars which have the furthest distance to run, and which are to be switched upon different sidings, may be sufficiently far apart at the end of that distance so that the last switch may be easily thrown between them.

But since loaded cars move faster than empty ones, and, on the other hand, many cars move slowly on account of some defect (insufficient oiling, wear of axles, etc.), attention must be given to this, and the velocity with which the cars are moved out must be regulated accordingly. In the construction of switching tracks of this kind the distance which two cars have to run before being switched upon their respective sidings should be as small as possible.

At the Station Gereon it is possible during 24 hours to run out about 4 000 cars from one of these gravity tracks. However, a few

horses are always used to assist in accelerating the movement of the slowest cars, although the grades in general are very well arranged. The summit of these grades lies 3.60 m. (11.8 ft.) higher than the ends of the tracks, as these are in the public loading street and the freight shed is on the level of the neighboring streets. This difference in elevation is, with the exception of the grade of 2% in 50 m. distance, overcome by a grade of 1 in 200 in the switching yards and curves, and by a grade of 1 in 500 through the rest of the station. In order to arrange the cars of a train in the order of the several stations, a number of short tracks are placed on each side of the yard.

The switches are mostly operated from elevated switch houses, one of which has as many as 15 levers. Such a number must be regarded in busy times as extraordinarily large for one man to attend. This switchman sees the number of the track written upon the buffer of the car, and thus knows which lever is to be turned. In order that switches which are far distant from the switch house shall not be reversed in case a car is upon the switch rails, special pressure rails are provided which prevent it. The cars are brought to a standstill by means of wheel skids, which are made very strong, since the wheel, held fast by the skid, often slides along on the rail a distance of 10 to 15 m. (33 to 49 ft.).

Besides the two main freight tracks and the tracks for sorting, there are also two tracks for the movement of locomotives. Between the locomotive tracks and the main tracks, on the northeast side of the station, is the siding for the cars which carry supplies about the station. The tracks for the locomotives are extended beneath the main line toward Bingen and under a part of the traffic station, terminating in a round-house, having room for 30 freight locomotives.

The arrangement of this round-house is similar to that at the traffic station. The locomotives are furnished with coal from the elevated coaling bins at the traffic station, the coal cars arriving at the traffic station being dumped into smaller coal cars standing on a level 1.5 m. (4.9 ft.) lower. These small coal cars, each containing a definite quantity of coal, are, by tipping, dumped directly into the tenders.

The locomotives are supplied with water from the city water works. However, in order that the supply may not fail in case of an accident to the city works, a tower has been built near the round-houses. This tower supports a reservoir, built according to the system of Professor

Intze, of Aix-la-Chapelle, which contains 600 cu. m., and which is placed at such a height that the locomotives of the high elevated passenger round-house can also be readily supplied with water. The reservoir has not been encased to protect it against frost, since there is no danger of freezing when in continual use.

A repair shop for the locomotives is situated near this round-house, but extensive repairs are made in one of the main shops of Cologne. For the smaller repairs of the cars a workshop is situated at the end of the switching tracks.

(*b*) *The Local Freight Business.*—All the freight in less than carload lots which arrives at the Station Gereon is unloaded, and this is done in the main freight shed.

In the year 1889 the local freight received at Gereon averaged 168 tons, and that shipped 184 tons, while 162 tons were transferred at the freight shed. From these numbers it is to be seen that arrangements had to be made, to accommodate many cars in the shed. For this purpose there was erected in front of the shed a system of turn-tables, which lead to the loading platforms. On each side of these platforms two cars can be handled simultaneously. The shed has a length of 200 m. (655 ft.) and a breadth of 40 m. (131 ft.). In total, 48 cars can be loaded or unloaded at the same time. The shed was made extraordinarily wide in order that freight which was to be unloaded in special places should not have to move too long distances. The shed has solid walls and a high roof, covered with a double thickness of roofing felt; it is lighted throughout along the ridge and also on each side by gable windows between each pair of trusses. Adjoining is the shed for customs freight, which is similarly constructed, and has room for loading and unloading 10 cars in a similar way.

Freight particularly liable to take fire is stored in a special shed in the neighborhood of Erft Street, which is built entirely of iron and corrugated metal.

To accommodate the public, a number of so-called loading streets are provided. The tracks on these are separated 14.5 m. (47.6 ft.) apart. In total, about 220 cars can be loaded or unloaded.

On Erft Street there are also cattle pens, but these are unimportant in comparison with those now being built by the city of Cologne.

The outdoor lighting of the Station Gereon is for the most part by electric lights, while the offices and sheds are lighted by gas. Since

the principal work of making up trains is done at night, care has been taken to provide sufficient light.

VII. The Freight Station, South Cologne.

The freight station at South Cologne is served by a special track from the Station Gereon, but a connection with the main track is wanting. For this reason small articles of freight are not sent directly to South Cologne, although such are received in the freight shed there. The principal business at this station consists in unloading carloads of freight. On the loading streets there are tracks on both sides, 14 m. (46 ft.) apart, so that 160 cars can be loaded and unloaded at the same time. The station is connected with the neighboring streets, whose surfaces are 4 m. (13 ft.) deeper, by approaches having grades of 1 in 30.

VIII. The Street-Crossings.

The iron structures of the street-crossings are partly of arched trusses and partly of plate girders. With the plate girders continuous spans are avoided. Girders with projecting ends, which support a central span, are preferred. The joints where the independent span rests upon the projecting end are so constructed that only very slight bending moments can be transferred. In the computation of the arched trusses they are regarded as having hinges at the crown and at the springing lines, but the hinge is not actually inserted at the crown, although it has been the aim to arrange the connection and the splice plate so that a hinge action may exist. To secure a thick floor, buckle plates were used. In the middle of the buckle plates is a hole, by which the drainage is led to a gutter. The buckle plates are covered by a layer of gravel about 0.3 m. (1 ft.) thick, and upon this the iron crossties which support the rails are laid.

In order to secure good light, the masonry walls are mostly faced with white porcelain tiles.

The span of the structure across main streets is 20 m. (65.5 ft.), while for less important streets it is 15 m. (49 ft.).

IX. Construction.

As already mentioned, the general plan for the reconstruction of the railroads in Cologne was in 1883 so far developed that in that year the Prussian House of Deputies appropriated the sum of 24 500 000

marks ($5 900 000) for its execution. After the greater part of the real estate had been purchased, in 1885, construction was begun on that part of the work which was not connected with the old tracks and stations. In particular this included that part of the roadbed and the street-crossings along by the new ramparts. At the same time the tracks in the old part of the city were so moved that half of the elevated structure for the new tracks could be built. In this way it was possible, by the use of several temporary tracks, to bring into service two elevated tracks. First, the trains for the right bank of the Rhine and those for Aix-la-Chapelle and Crefeld were brought upon these tracks, while those for the lines to Coblenz and Trier continued to run on the old roadbed. After a short time it was possible to bring these, also, upon the new elevated tracks and into the new station The entire ticket and baggage business was transferred temporarily to rooms under the elevated structure on Maximinen Street; waiting-rooms and offices for trainmen were temporarily put up, so that the old reception building could be torn down and the erection of the new one be carried on. The corner-stone of the new reception building was laid May 7th, 1892.

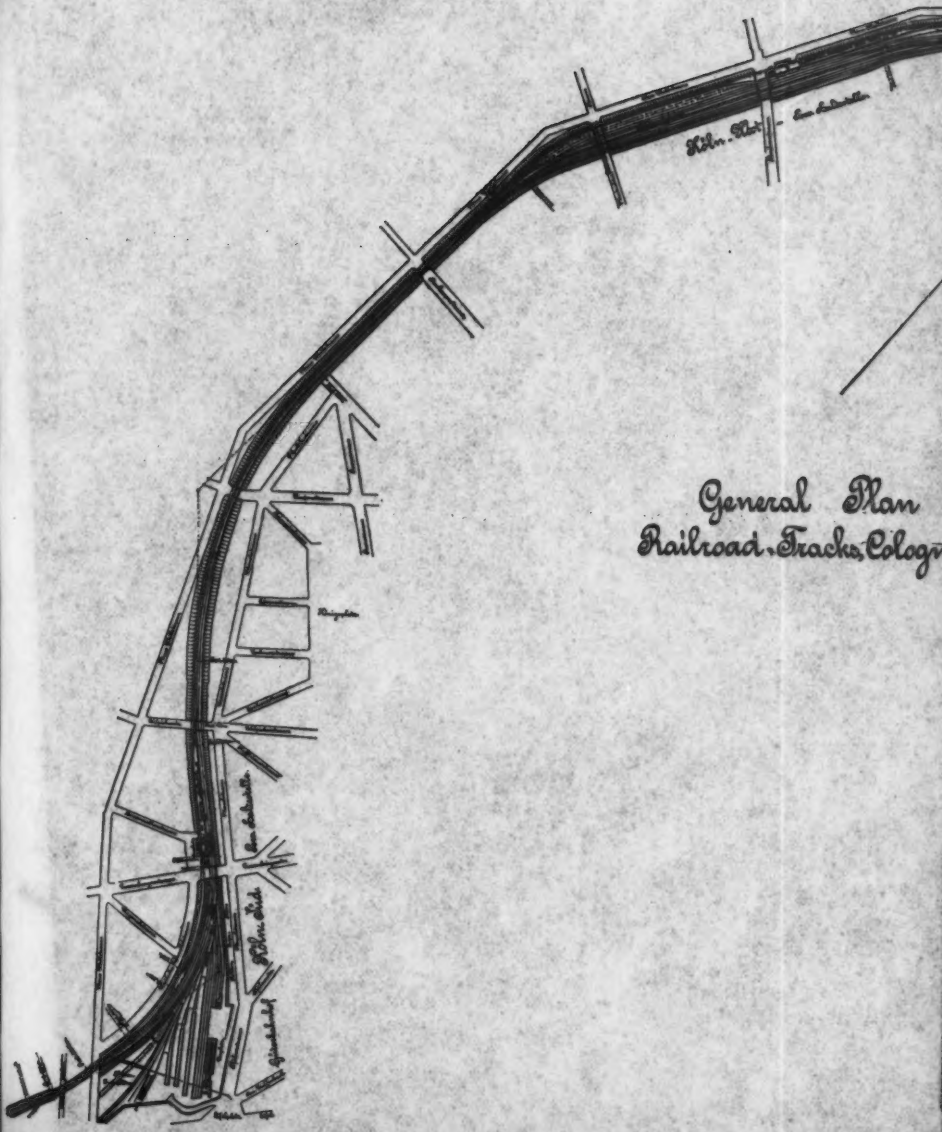
Meanwhile the new Station Gereon was built by additions to the old building, and brought into service; but the traffic and the small freight still remained at the old station. In this manner every foot of ground which was taken from the old system had been previously replaced by the new system, so that the entire construction was carried on step by step and in systematic order.

In the year 1892 there was appropriated 7 400 000 marks ($1 700 000) additional, for extensions unforeseen in the original plans, so that the entire probable cost is 31 900 000 marks (about $7 600 000), divided as follows:

	Marks.
Real estate	11 000 000
Earthwork and elevated tracks	2 000 000
Bridges and street-crossings	4 500 000
Buildings	10 000 000
Superintendence	1 000 000

and so forth.

At present the construction is so far advanced that the completion of the entire work may be reasonably expected by the close of the year 1894.



General Plan
Railroad-Tracks Cologn

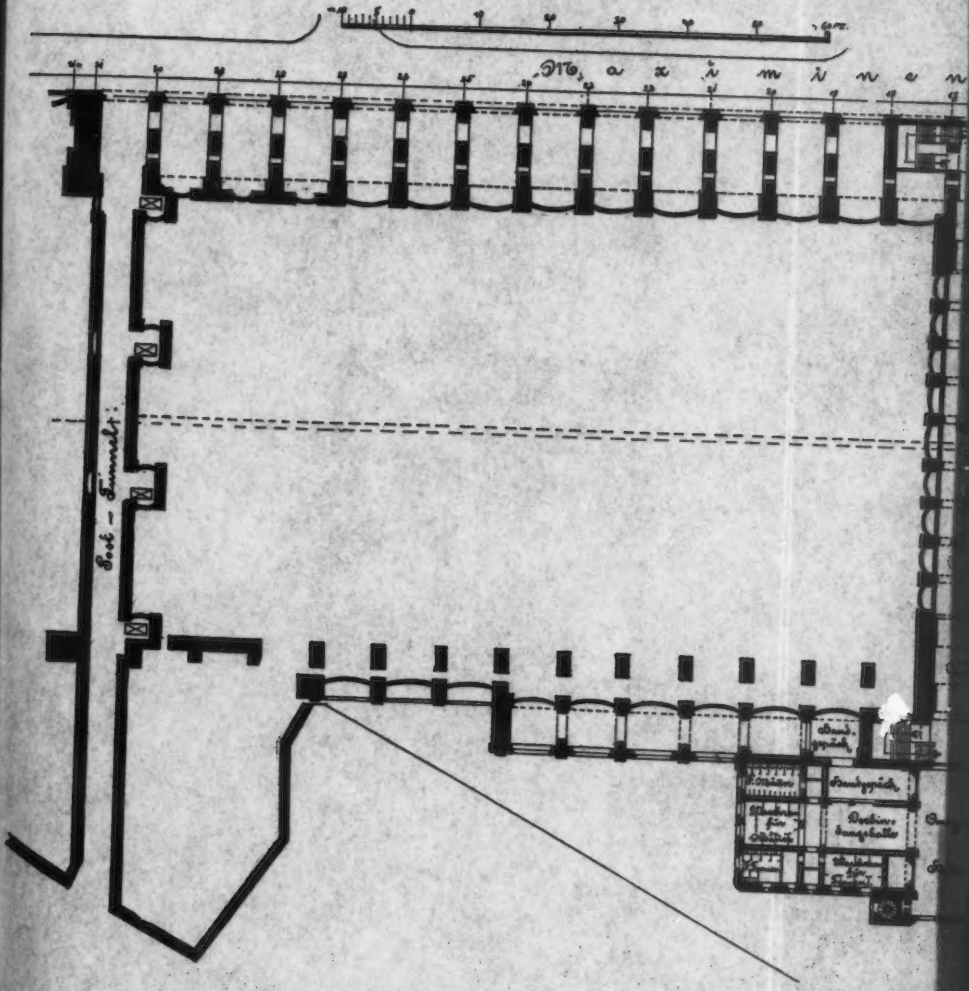
eral Plan
. Tracks, Cologne.
Rheinbrücke nach D

NGRS.
TIONS IN COLOGNE.

ach Deutz.

Hauptbahnhof Köln.

Grundriss des Erdgeschosses bezw. Unterbau.



Ce

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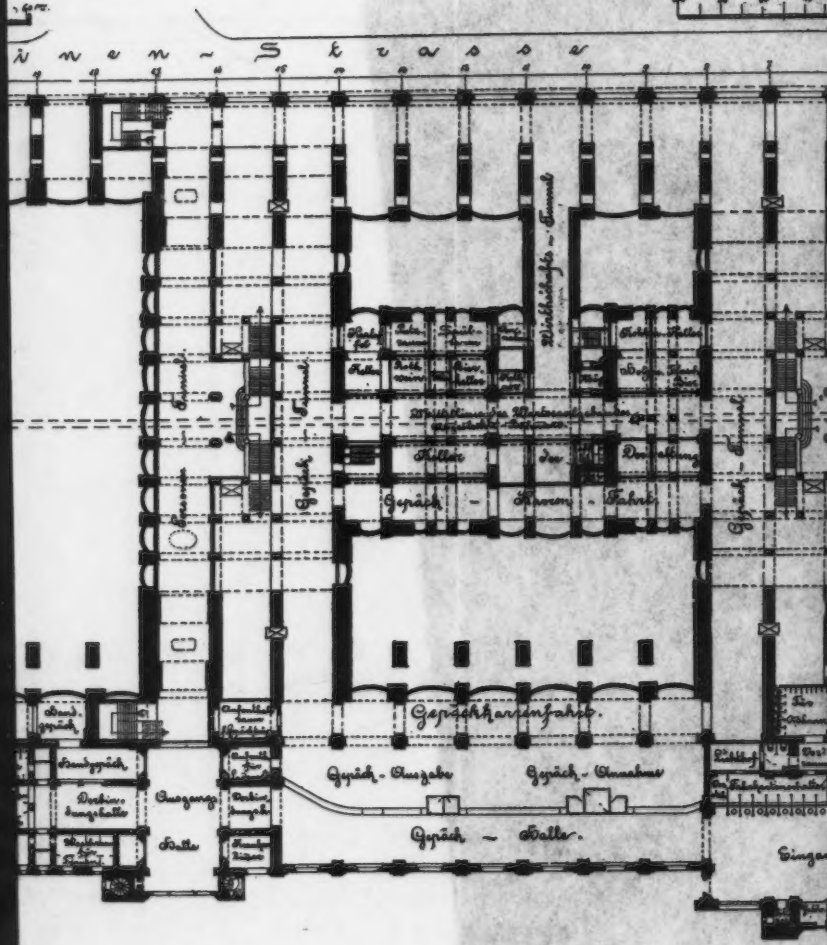
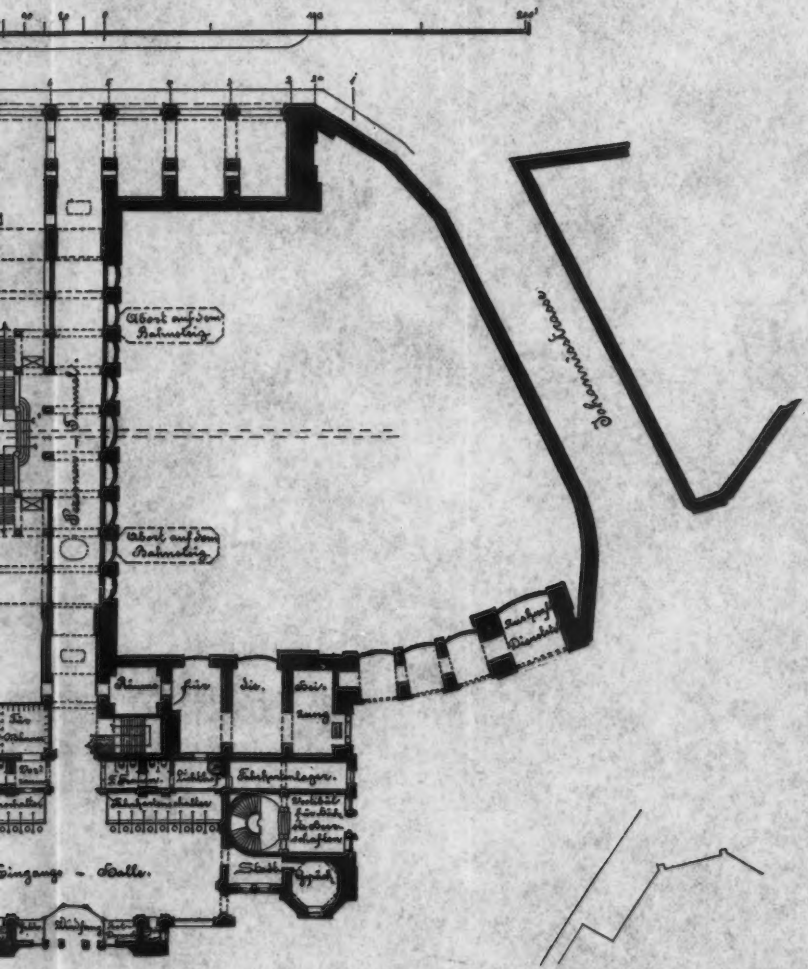


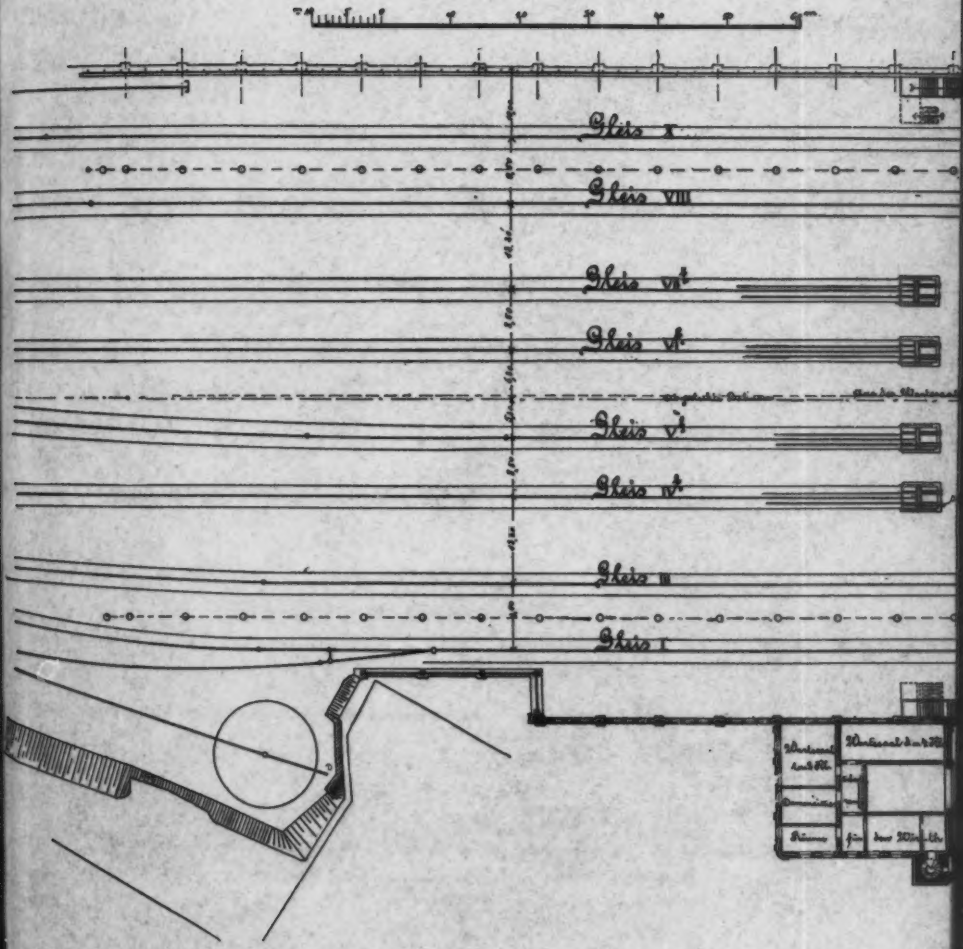
Central-Depot, Cologne.

und-floor resp. of the subconstructions.



Hauptbahnhof Köln.

Grundriss in Höhe des Bahnsteigs.



Central

Plan in th

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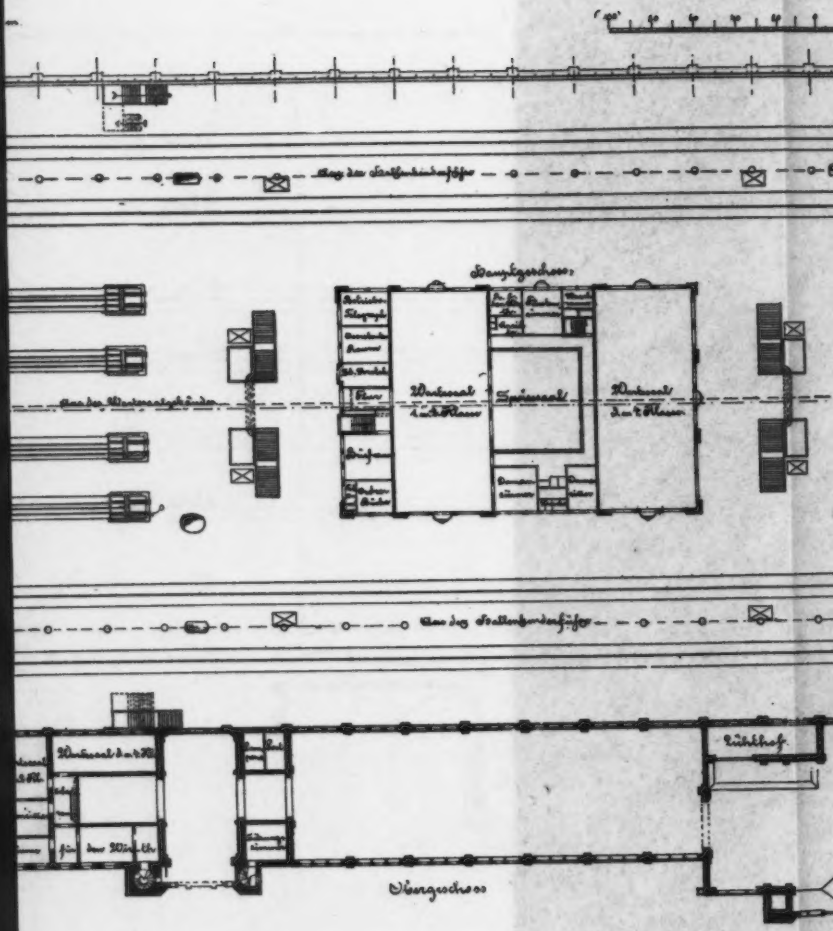
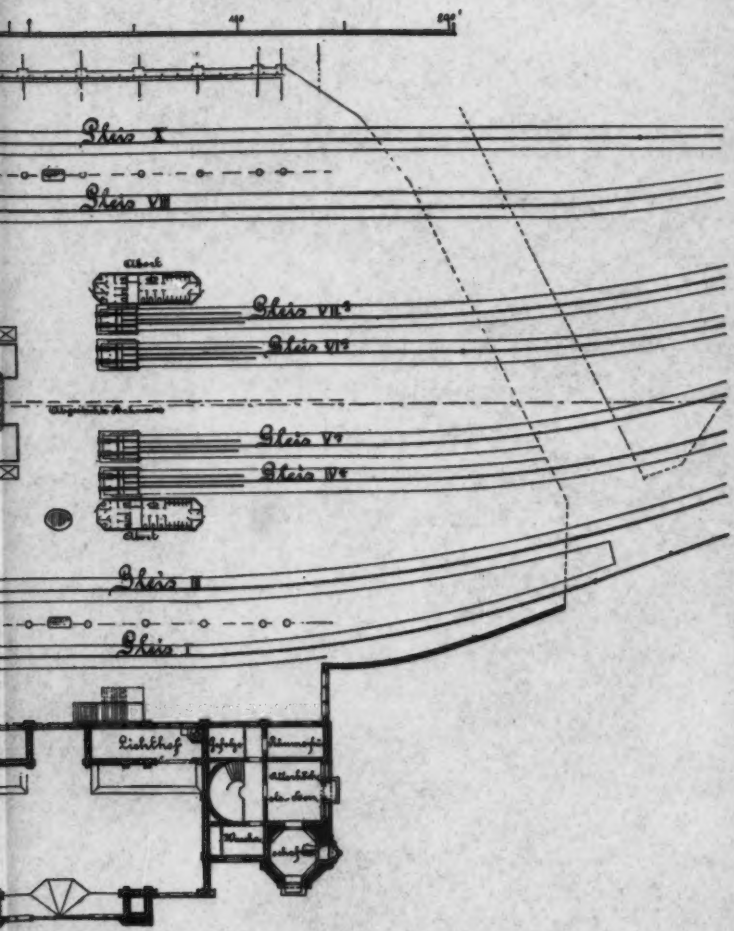


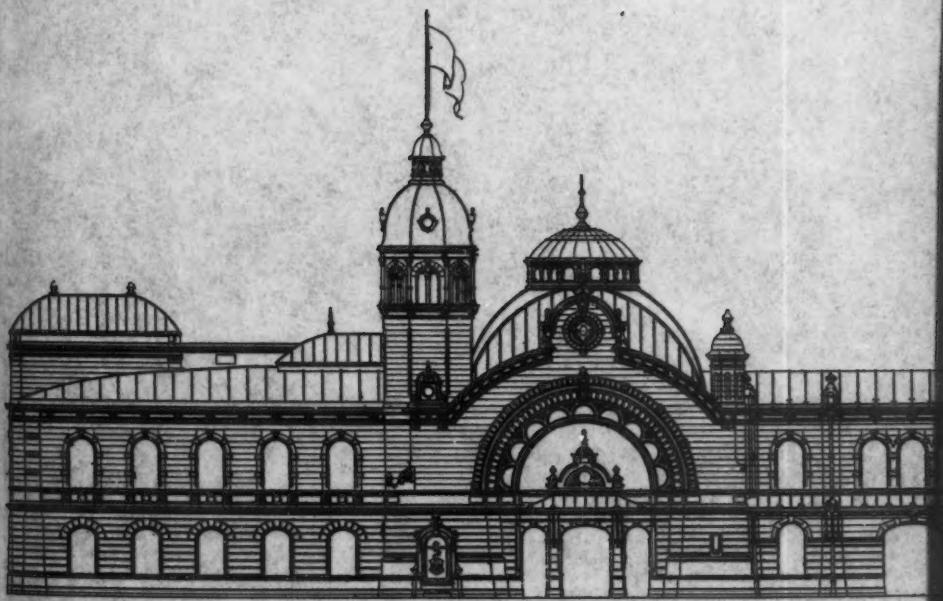
ral-Depot Cologne.

the level of platform.



Vordergebäude des Hauptbah

West-Ansicht.



ptbahnhofe: Köln.

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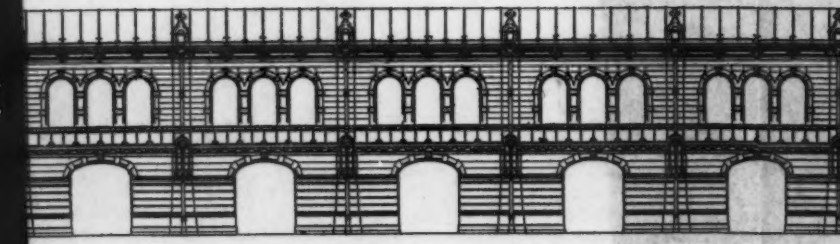
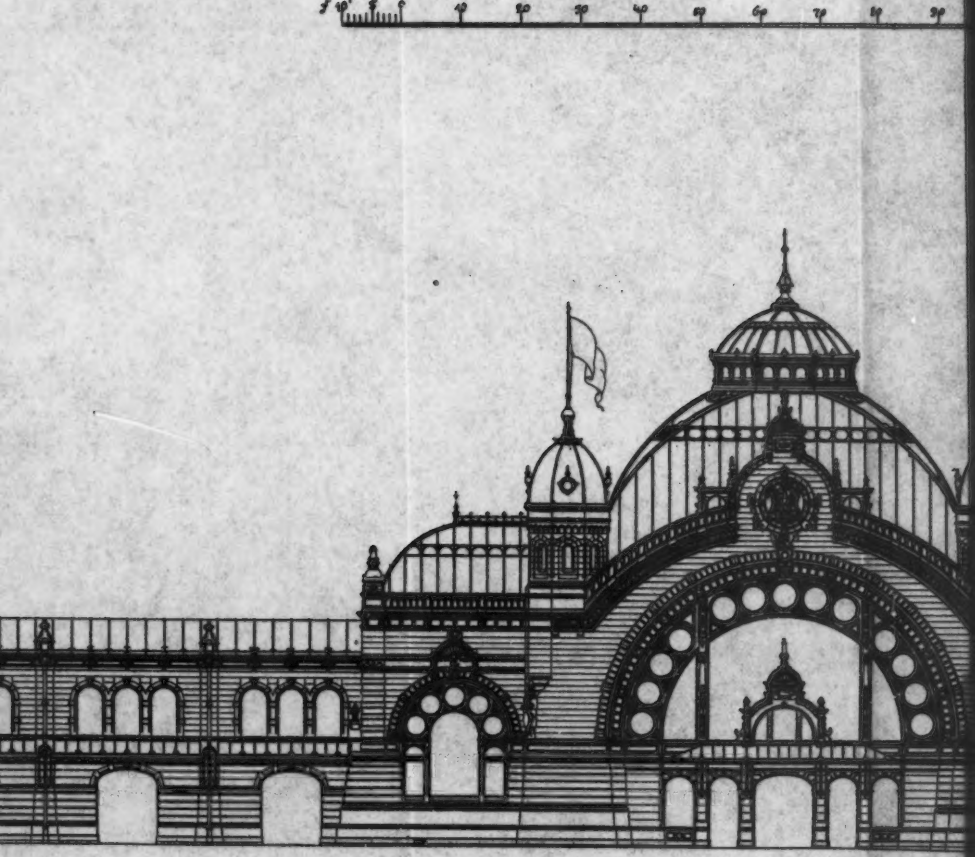


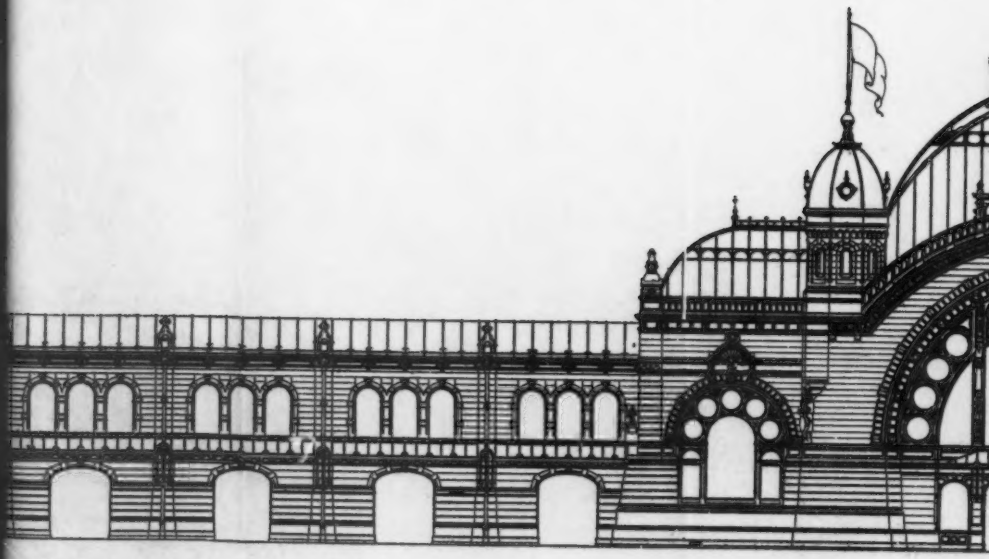
Main-Building, Central-

Elevation, We



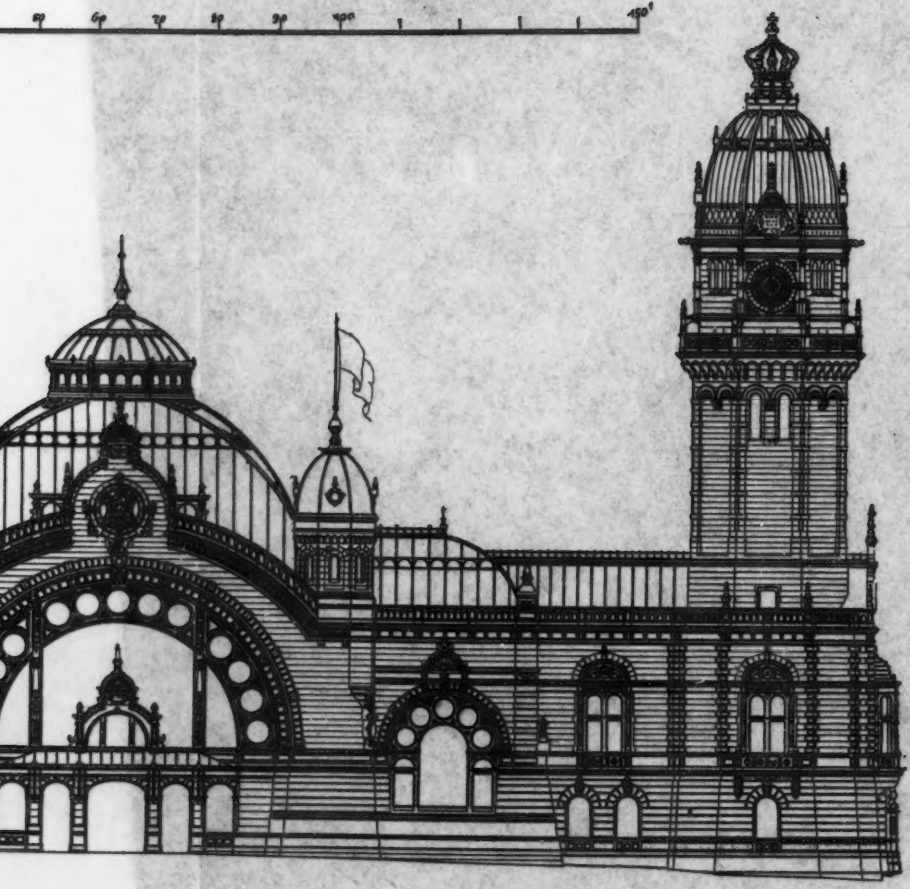
Main-Building

Eleva



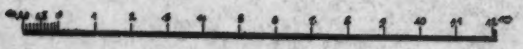
ng. Central-Depot Cologne.

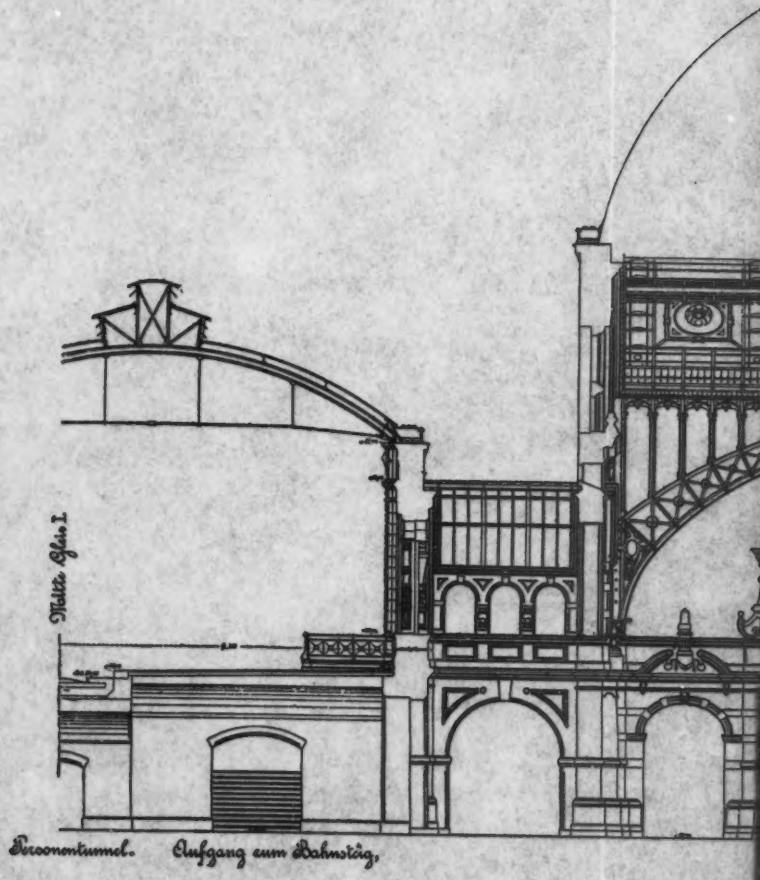
vation, West.



Vordergebäude des Hauptbahnhofes Köln.

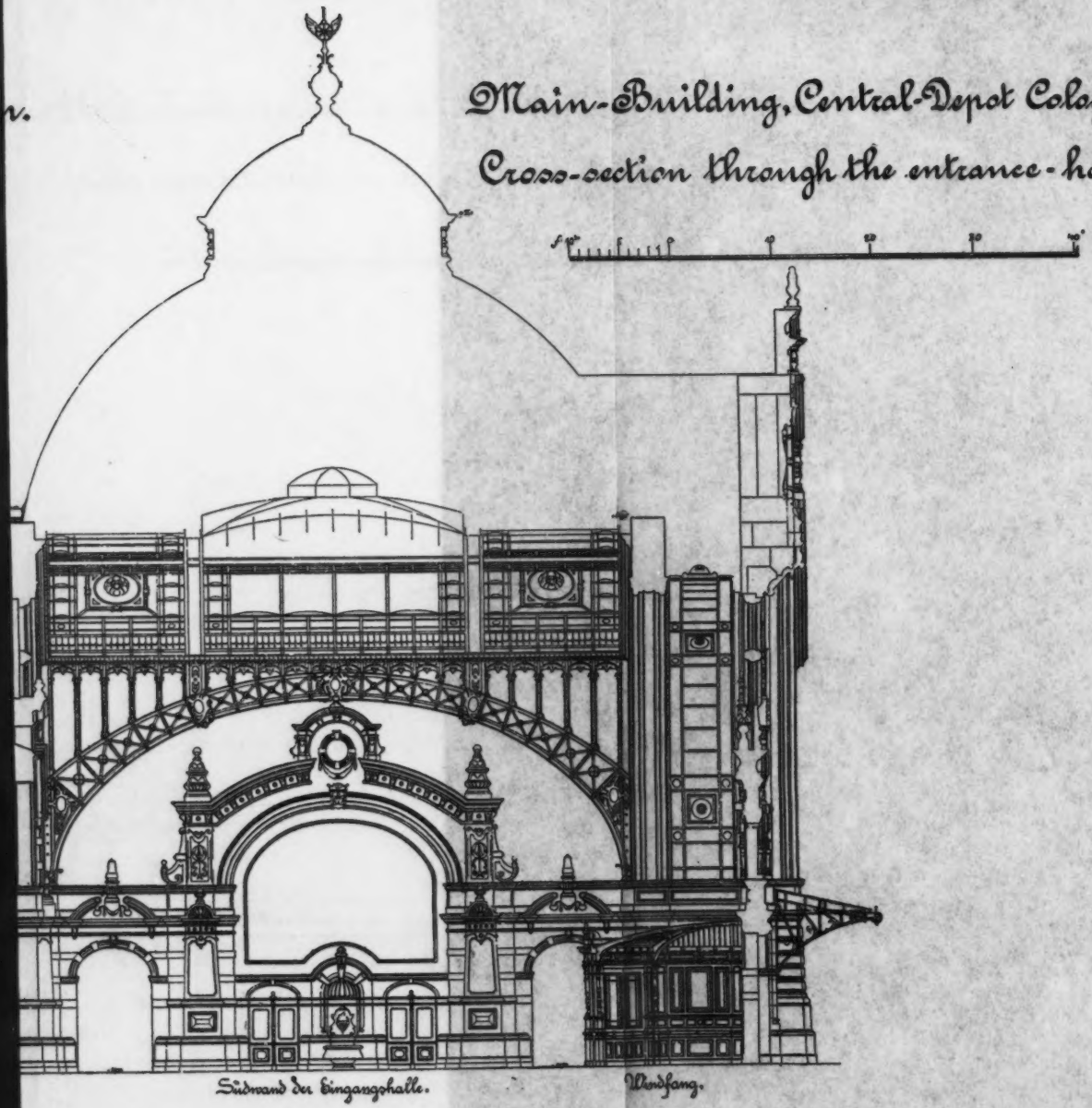
Querschnitt durch die Eingangshalle.





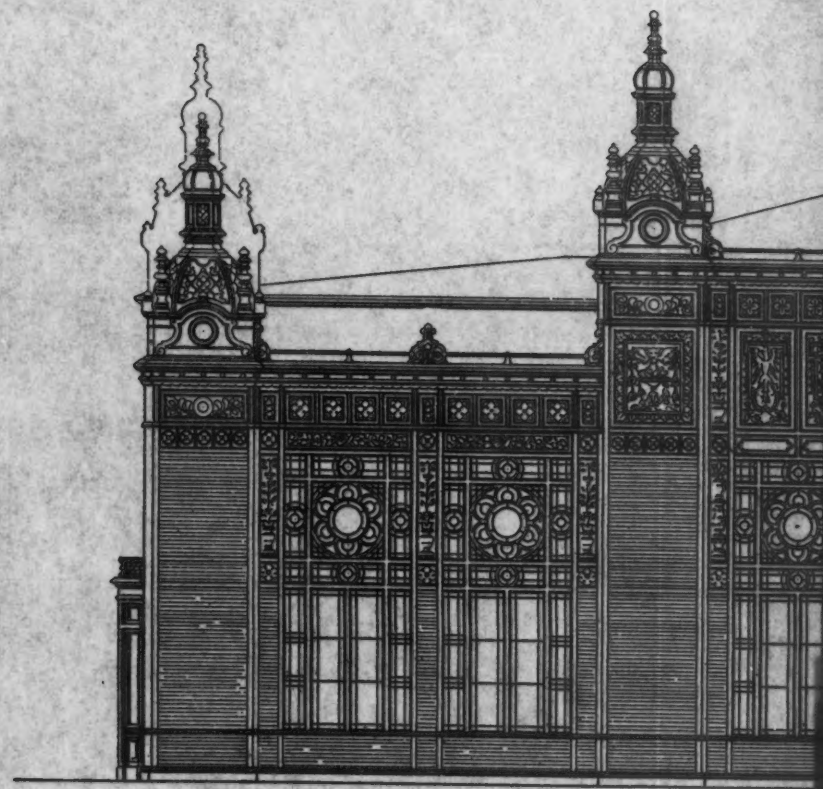
Main-Building, Central-Depot Cologne.

Cross-section through the entrance-hall.



Hauptbahnhof Köln.

Vorderansicht des Wartesaalgebäudes.



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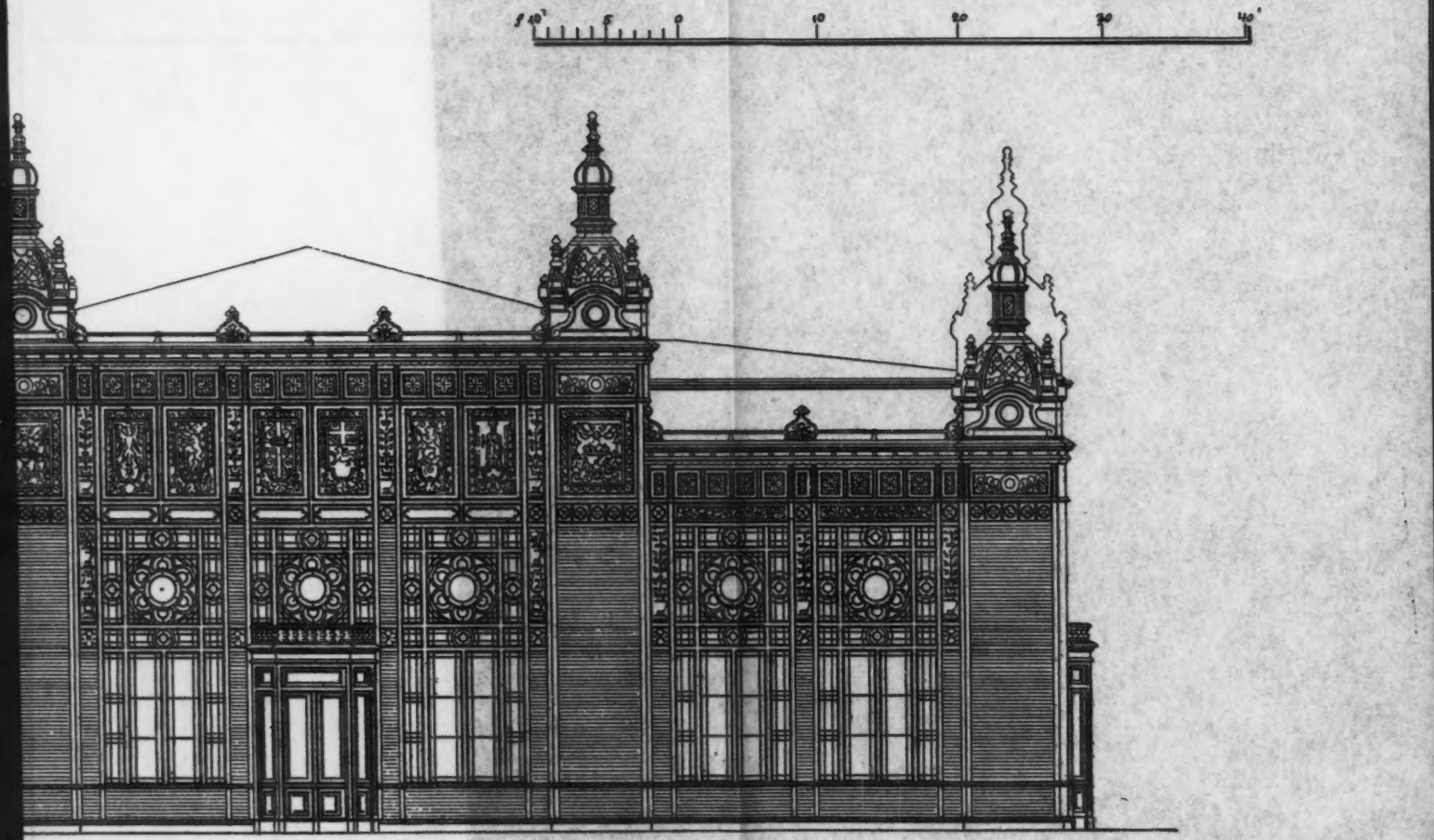
TRANS. AM. SOC. CIV. ENGRS.
LOHSE ON RAILROAD TRACKS AND STATIONS IN COLOGNE.
PLATE VI.

Central-Depot Cologne.

ländes.

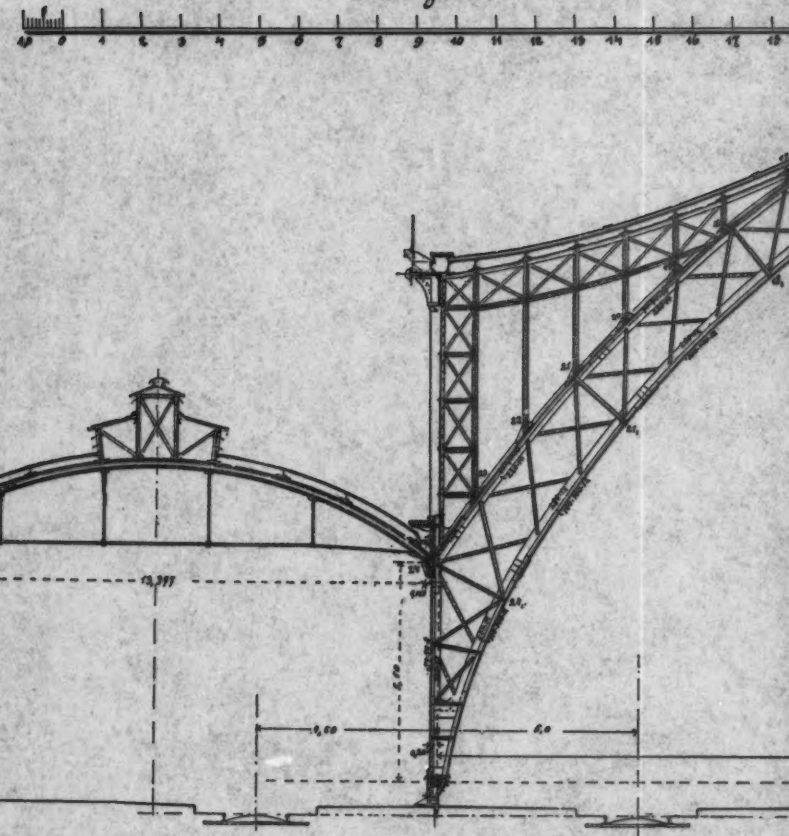
Front-elevation of the waitingroom-building.



Haupt-Personenbahnhof Köln.

Querschnitt durch die Bahnsteighal

Maafsstab.



Köln.

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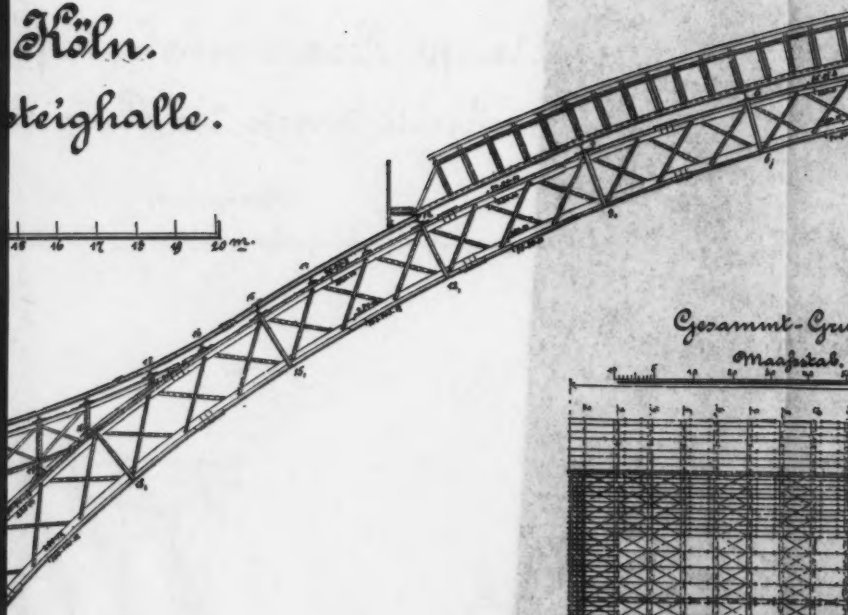
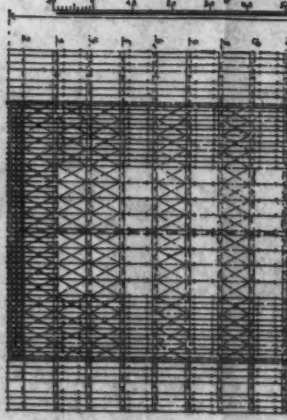
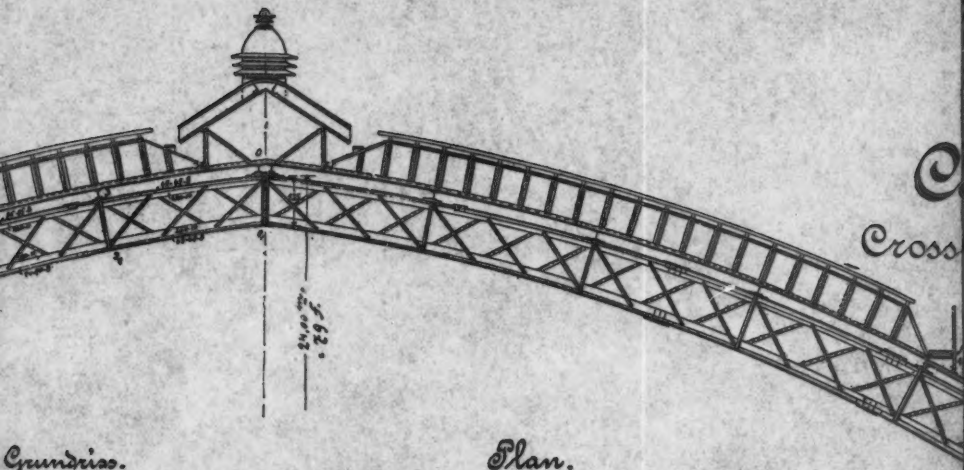


Gesammt-Gru

Maafsstab.



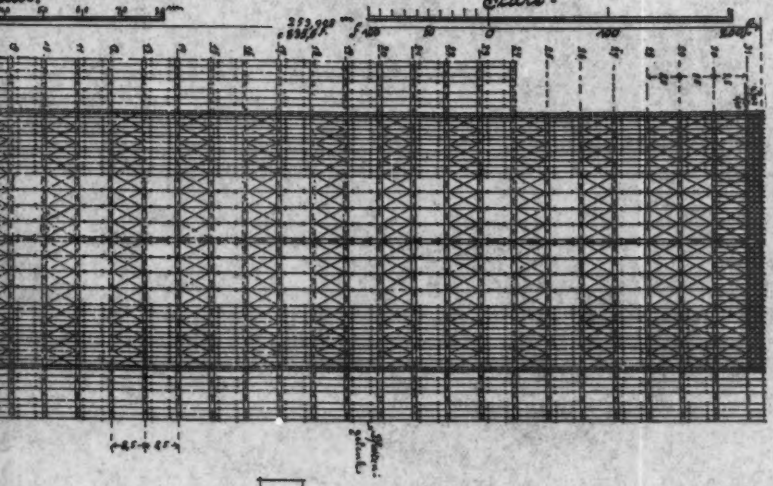


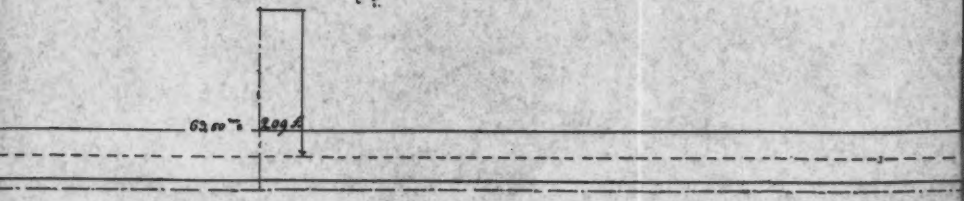
Cross

Grundriss.

Plan.

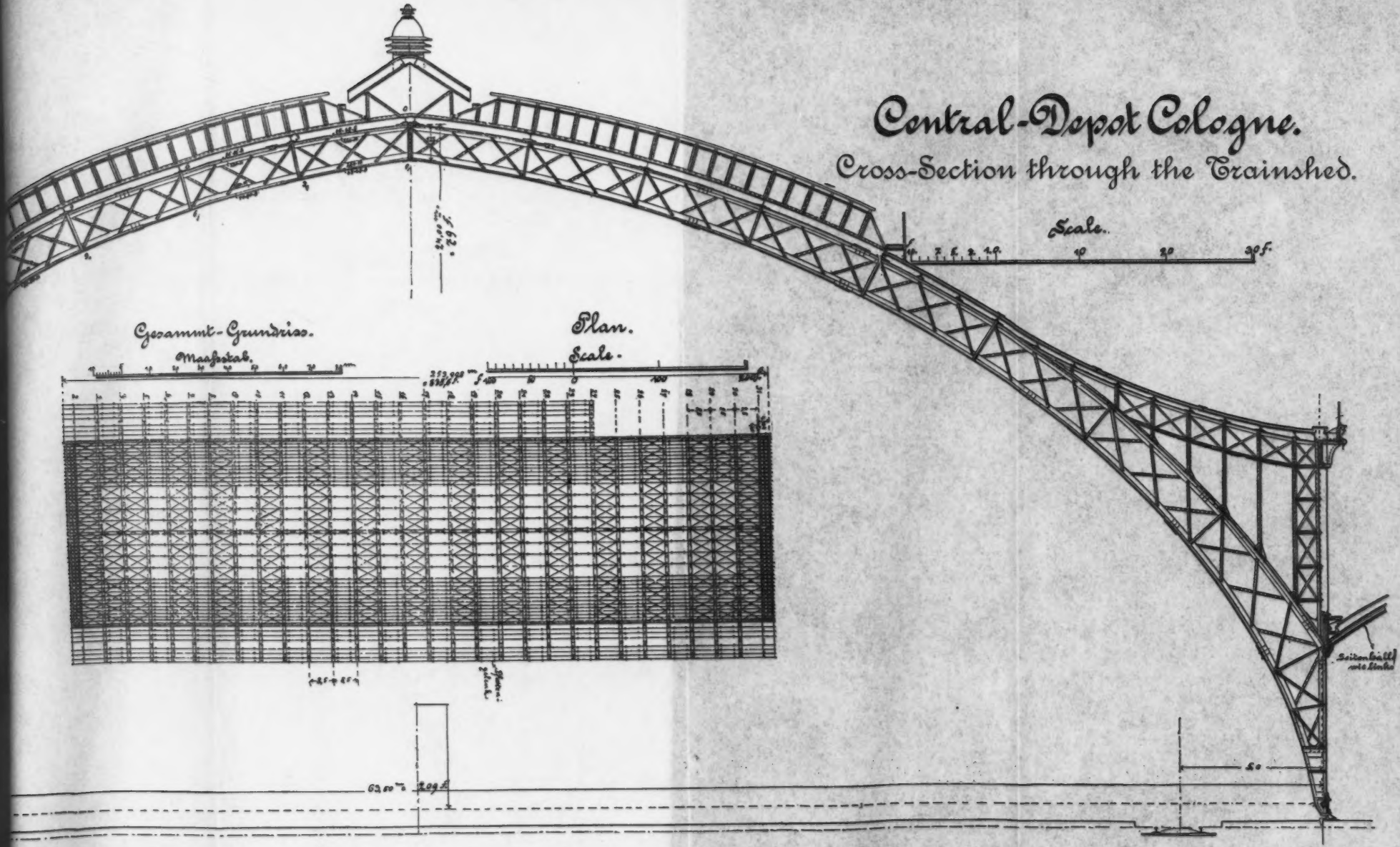
Scale.





Central-Depot Cologne.

Cross-Section through the Trainshed.



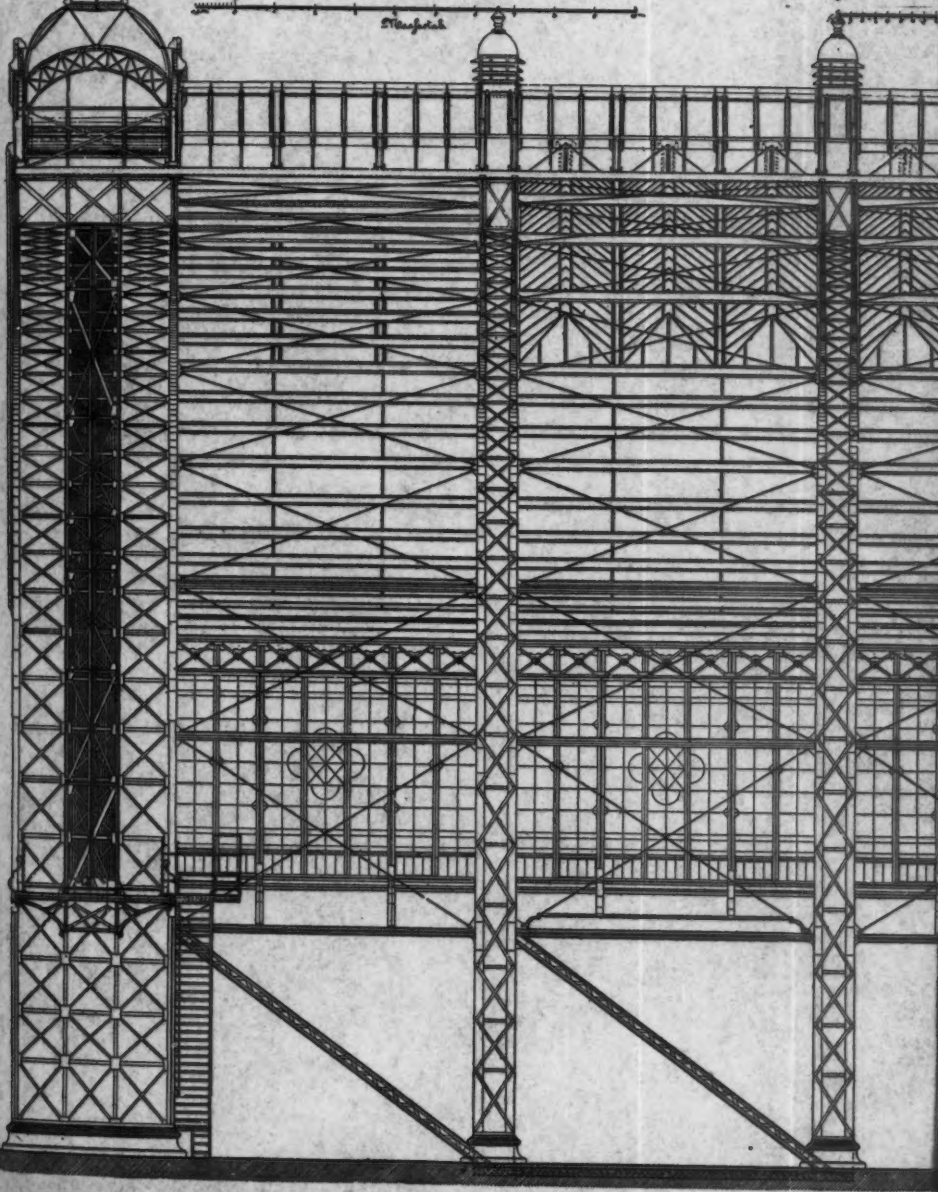
Haupt Personenbahnhof Köln.

Längenschnitt durch den Hallenscheitel.

Maßstab

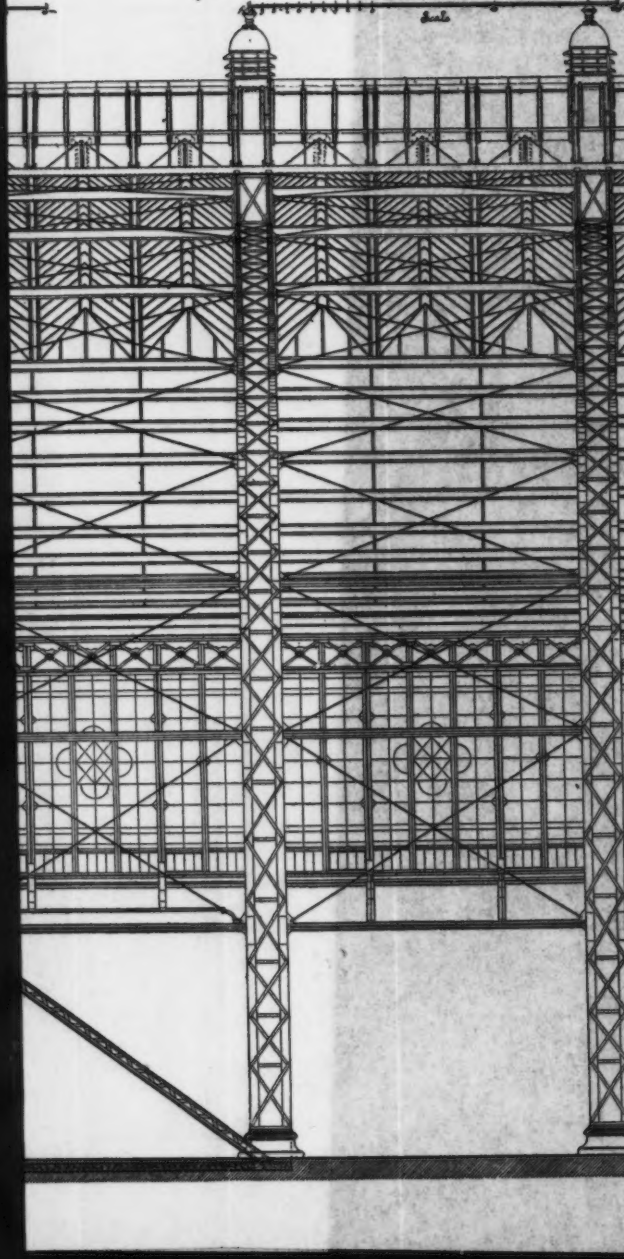
Cent

Longitudinal-S



Central-Depot Cologne.

Longitudinal-Section through the Transh



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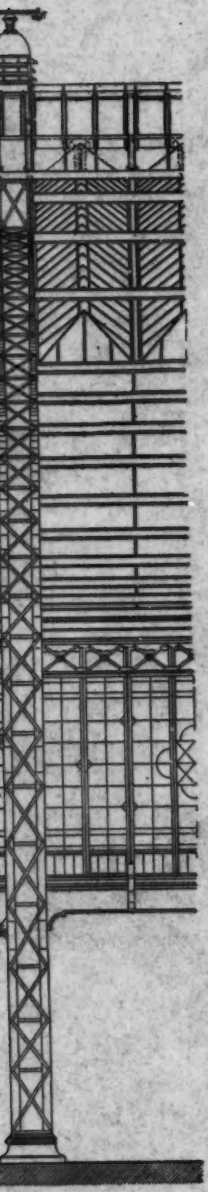
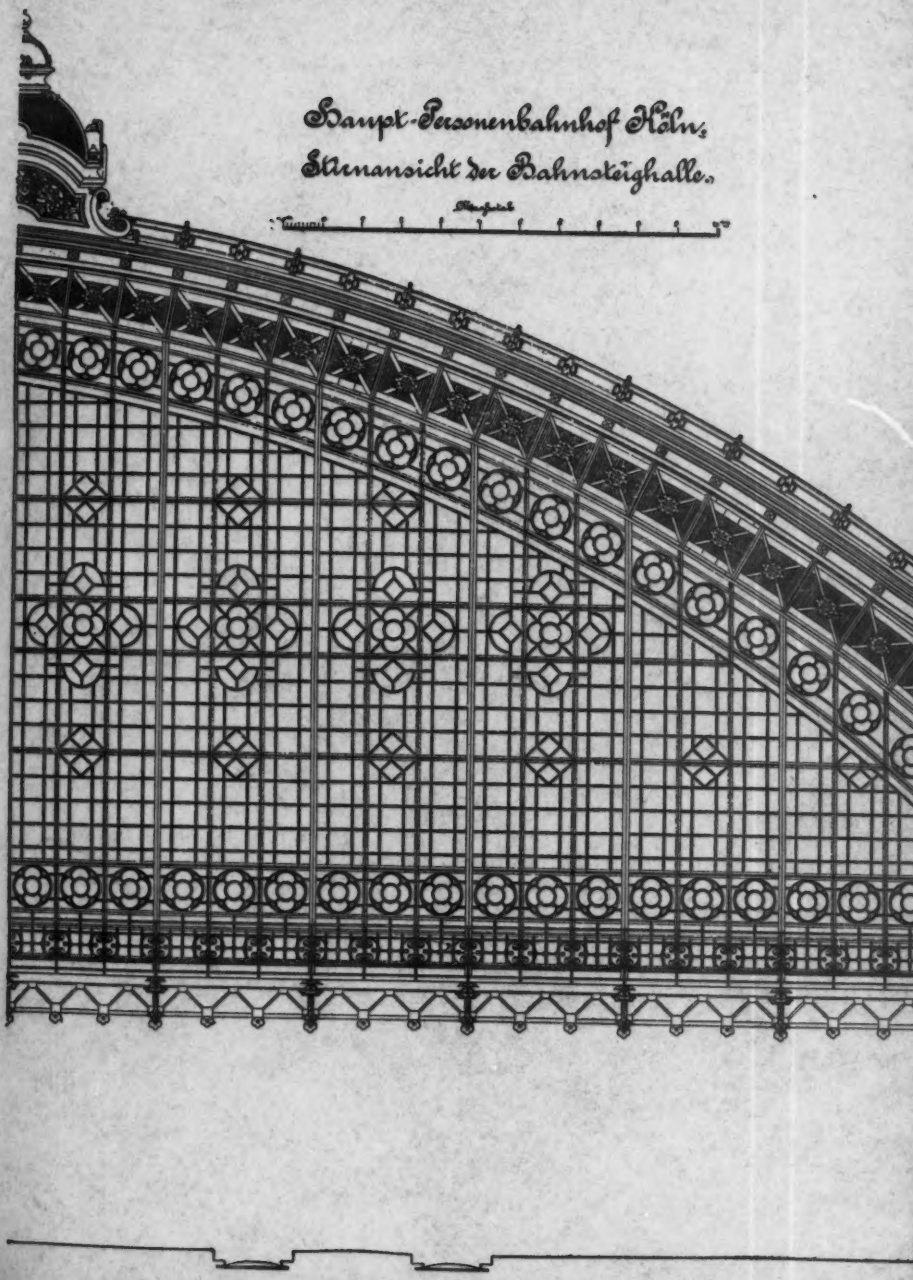


Haupt-Personenbahnhof Köln.

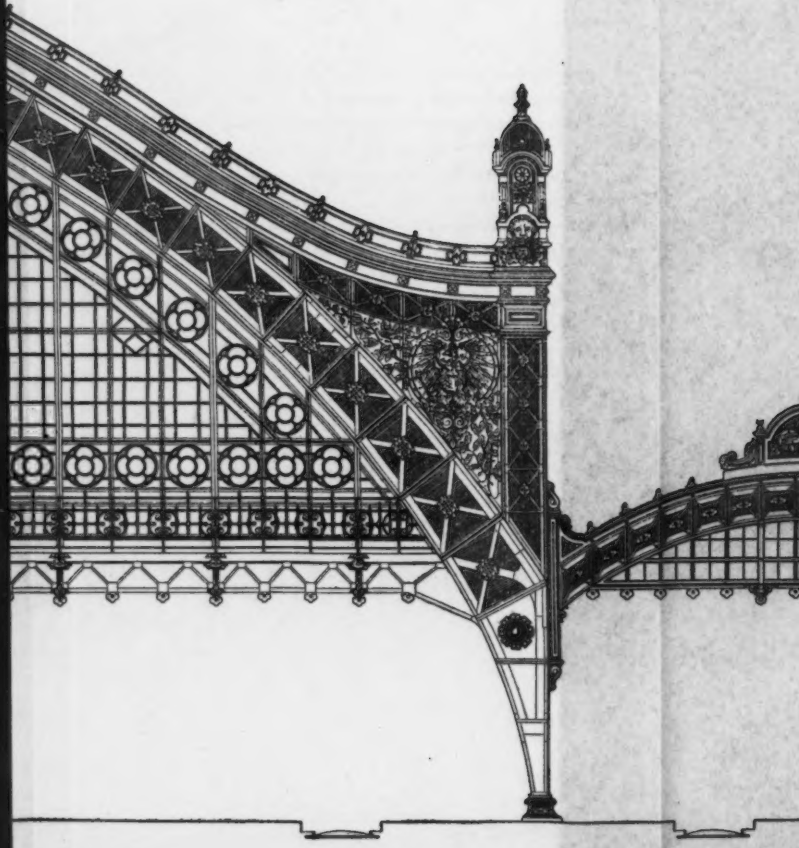
Stirnansicht der Bahnsteighalle.

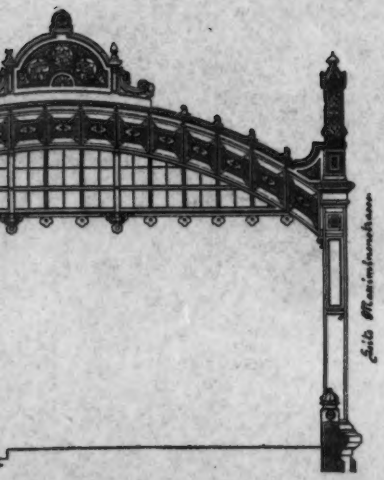


Central-Depot Cologne.

Front Elevation of the Trainshed.

Scale





The execution of the plans and the construction of the new system was first done by the Royal Railroad Board of Cologne (left bank of Rhine), under thedirection of Ober-Bau und Geheimer Regierungsrath Dircksen, so long as the work made but few encroachments upon the old system. But as continual changes in the movement of trains were demanded, in order to facilitate the construction, the further development of the plans and the conduct of the work was transferred to the Traffic Office Cologne-Düren, the General Manager of which is Regierungs und Baurath Blanck. At present Regierungs und Baurath Wessel has the direction of the work, while the Bureau of Architecture is in charge of Bau-Inspector Weithmann, and that of Engineering Construction in charge of Bau und Betriebs-Inspector Lohse. Among different engineers who have been engaged on designs and construction should be especially mentioned the Division Engineers Kiel and Baltzer.

The plans for the reception building of the main passenger station were made by Professor Frentzen, of Aix-la-Chapelle, while those of the waiting-room building and the train shed are due to Professor Jacobsthal, of Berlin. The latter has also been employed on many other problems of an architectural kind.

EXPLANATION OF THE MORE IMPORTANT GERMAN WORDS ON THE PLATES

Plate I.

Haupt-Personenbahnhof.....Main Passenger Station.
Dom.....Cathedral.
Rheinbrücke.....Rhine Bridge.
Betriebsbahnhof.....Traffic Station (auxiliary yard to Passenger Station.
Haupt, Güter und Verschiebebahnhof.....Main Freight and Switching Station.
Personen Haltestelle.....Local Passenger Station.

Plate II.

Eingangs-Halle.....Entranee Hall.
Fahrkarten-Schatter.....Ticket Office.
Gepäck-Halle.....Baggage Hall.
Gepäck-Annahme.....Outward Baggage Office.
Gepäck-Ausgabe.....Inward Baggage Office.
Ausgangs-Halle.....Exit Hall.

Plate III.

Wartesaal	Waiting-Room.
Speisesaal	Dining-Room.
Damenzimmer	Ladies' Room.
Fürstenzimmer	Royal Waiting-Room.
Stations-Vorsteher	Station Master.
Abort	Toilet-Rooms.
Lichtho	Light Well.
Obergeschoss	Upper Story.
Gleis	Track.

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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

612.

(Vol. XXIX.—August, 1893.)

THE REARRANGEMENT OF THE RAILWAY TERMINAL SYSTEM AT ALTONA, WITH SPECIAL REFERENCE TO THE AVOIDANCE OF GRADE CROSSINGS.

By R. CAESAR, Regierungs und Baurath, Member of the Royal Board of Railroad Directors at Altona, Prussia.

Translated from the German by WM. H. SEARLES, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The two cities of Hamburg and Altona, which unitedly have about 750 000 inhabitants, are built up so nearly together that it is impossible to tell where one city ends and the other begins (Plate II, Fig. *C*). From a commercial standpoint they are therefore to be regarded as one city.

In the plans for the reconstruction of the railway terminal system and the line connecting the two cities, which no longer met the requirements of the times, it was determined to take the trains entering Hamburg from the directions of Lübeck, Berlin, Hanover, Bremen and Cuxhafen further on over the four tracks of the Connecting Railway, and let them stop at the Altona Terminal. In this manner it became

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

possible to distribute the passengers at the various depots of the Connecting Railway, to discharge them as near as possible to their dwellings, and to relieve the main station of a portion of the traffic. On the other hand, trains coming from the north, that is, from Glückstadt, Flensburg and Kiel, and running into the Altona Depot, will be carried for the very same reason over the Connecting Railway to the main station of Hamburg. All through trains, as well as the suburban trains from the above-mentioned lines, are to use, on the Connecting Railway, the two south tracks, while the two other tracks serve exclusively for the city traffic, and for the Blankenese traffic therewith connected.

The depot of Altona is therefore:

1. In regard to through traffic—
   - *a.* The terminal depot for the lines entering from the direction of Hamburg.
   - *b.* A through station for the northern traffic.
2. Regarding the city traffic it is—
   - *a.* Terminal station for the purely city trains.
   - *b.* A through station for the trains running between Blankenese (a suburb) and Hamburg.

Since the main station at Altona, for local reasons, had to remain a head, or pocket, station, there resulted, through the chosen arrangement and the before-mentioned conditions of trade, a large number of grade crossings of tracks. These were considerably increased by the fact that on the northern tracks, outside of the passenger depot of Altona, a switchyard had to be established, at which all the freight trains of the various lines terminate and begin their course; and that from the same, therefore, there had to be established the following independent connections (Plate I):

- *a.* In the direction of Hamburg with the through tracks of the Connecting Railway, which, at the same time, serve as freight train tracks (*A*, *B*, *C*, on Plate I).
- *b.* In the direction of Altona and its harbor, with the local station of Altona and the harbor tracks (*A*, *B*, *E*, *F*, on the plate).
- *c.* In the direction of Blankenese with the Blankenese passenger train tracks (*G*, *H*, on the plate).
- *d.* In the northerly direction with the main tracks of the northern line (*I*, *K*, on the plate).

Grand Junction Station.

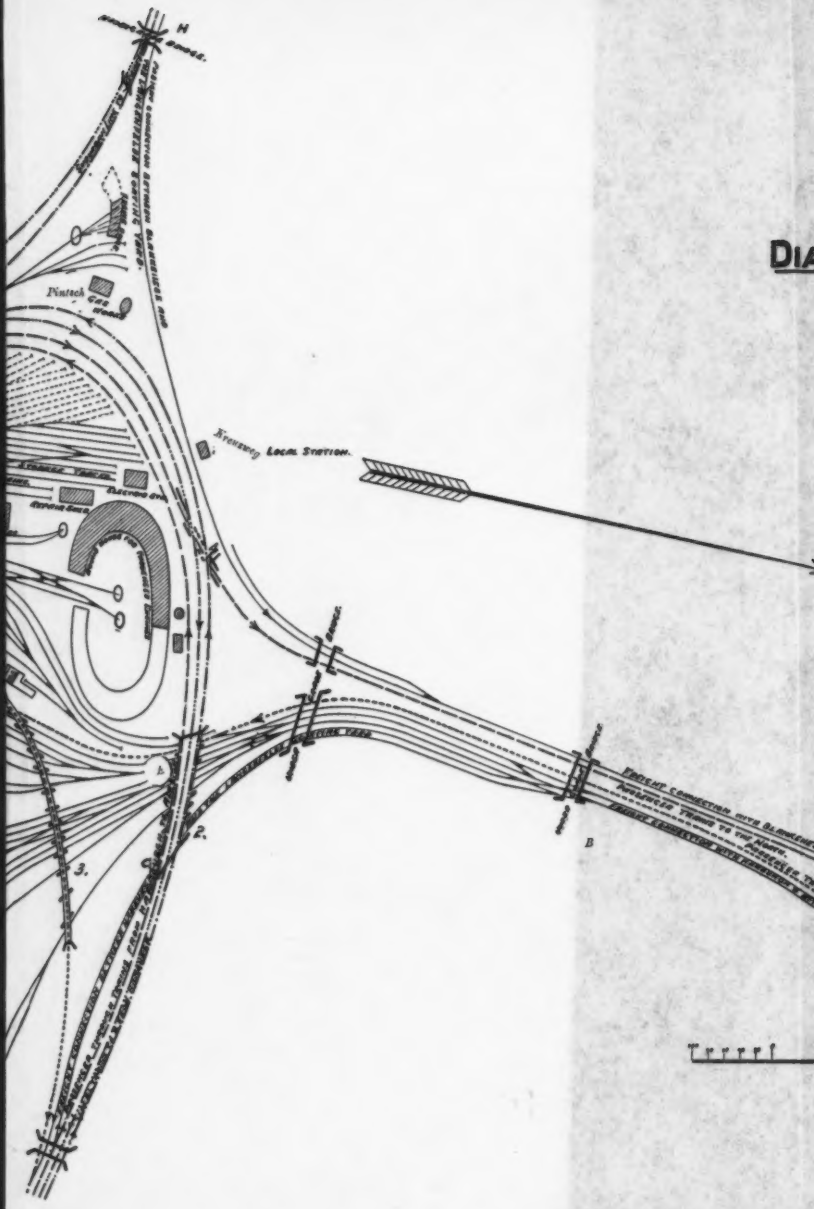

Fintech
Kirkby Local Station.
2.
3.

DIAGRAM SHOWING THE CONNECTION OF RAILWAY TRACKS IN COURSE OF CONSTRUCTION AT ALTONA, GERMANY.

— A. —

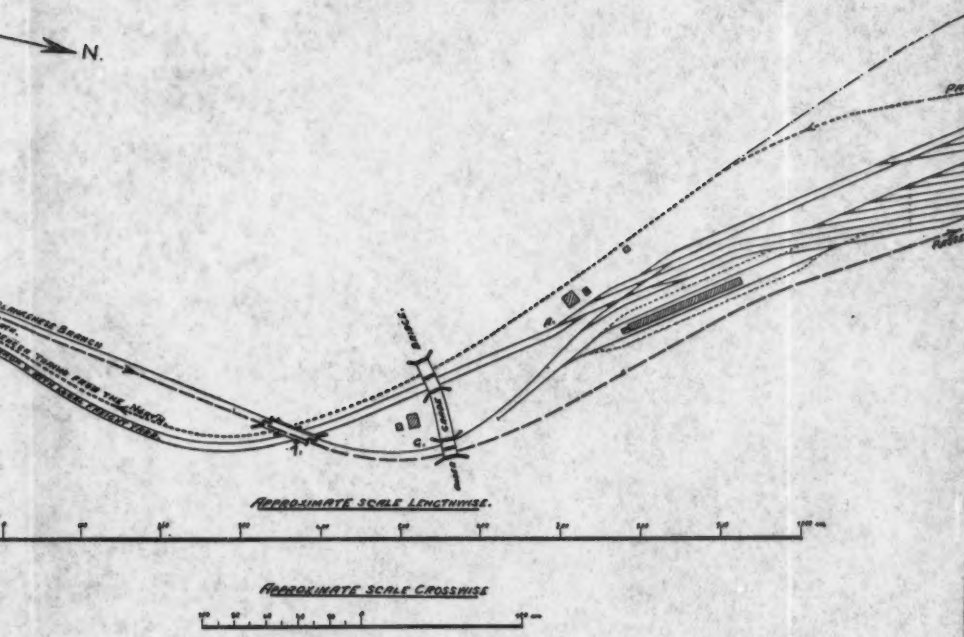
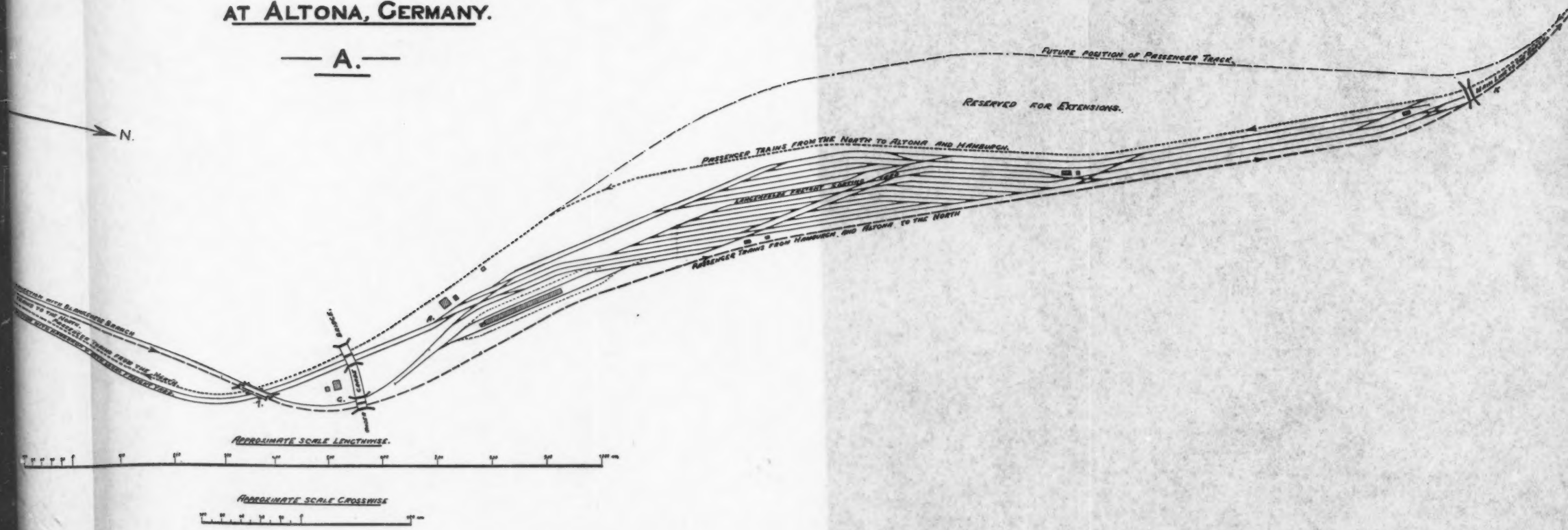
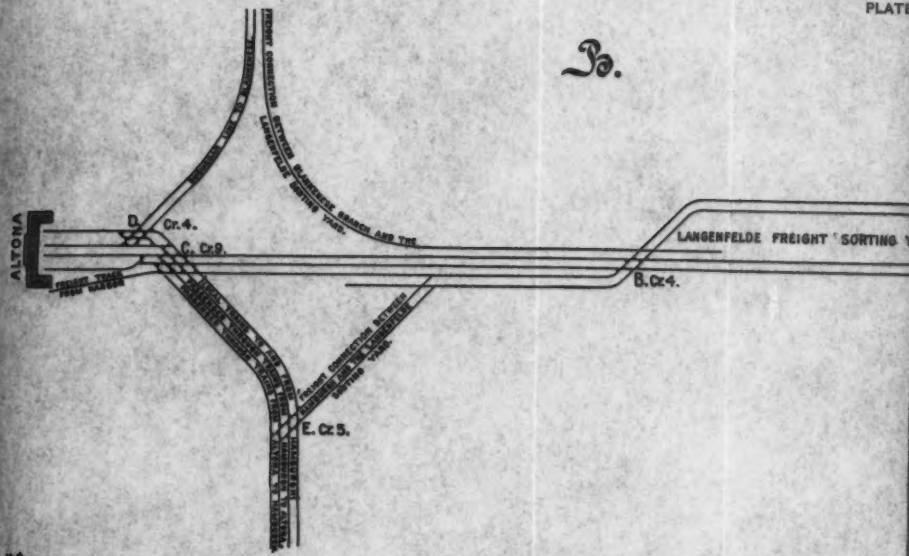


DIAGRAM SHOWING THE CONNECTION OF RAILWAY TRACKS IN COURSE OF CONSTRUCTION AT ALTONA, GERMANY.

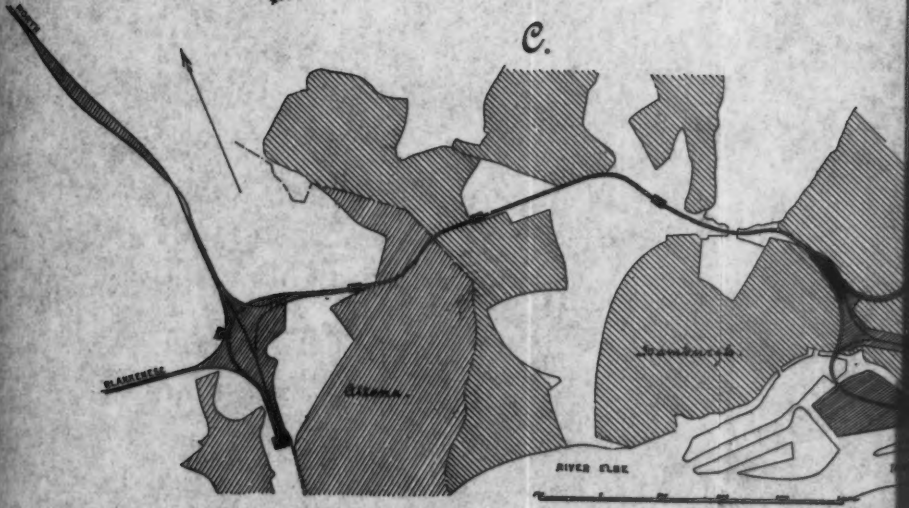
— A. —


N.
FUTURE POSITION OF PASSENGER TRACK.
RESERVED FOR EXTENSIONS.
PASSENGER TRAINS FROM THE NORTH TO ALTONA AND HAMBURGH.
PASSENGER TRAINS FROM HAMBURGH AND ALTONA TO THE NORTH
APPROXIMATE SCALE LENGTHWISE.
APPROXIMATE SCALE CROSSWISE

B.


ALTONA
D.
Cr. 4.
C. Cr. 9.
LANGENFELDE FREIGHT SORTING
B. Cr. 4.
E. Cr. 5.

C.


RIVER ELBE

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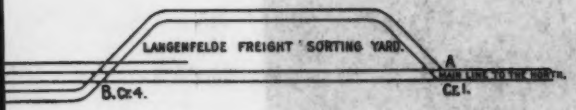
CAESAR ON RAILWAY TERMINAL AT ALTONA.
PLATE II.

B.



C.

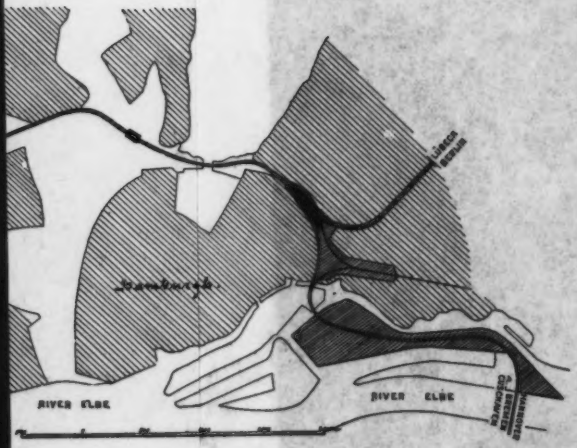


Fig. *B*, Plate II, shows, in an exaggerated plan, what would have arisen had all the grade crossings been retained. If we follow particularly the course of the passenger trains, it appears that the number of crossings with main passenger and freight tracks would be:

I.—For each train on the tracks set apart for city traffic—

1. From Hamburg, *via* Altona, to Blankenese—

At point	*E*	of the	sketch *B*	2
"	*C*	"	"	3
"	*D*	"	"	1
			Total	6

2. From Blankenese, *via* Altona, to Hamburg—

At point	*D*	of the	sketch	1
"	*C*	"	"	3
"	*E*	"	"	2
			Total	6

II.—For each through train on the southern tracks—

1. From Hamburg, *via* Altona, to the North—

At point	*E*	of the	sketch	1
"	*C*	"	"	3 + 3 = 6
"	*B*	"	"	2
			Total	9

2. From the North, *via* Altona, to Hamburg—

At point	*A*	of the	sketch	1
"	*B*	"	"	2
"	*C*	"	"	3 + 1 = 4
			Total	7

Now, the train traffic upon both passenger and freight tracks, immediately upon completion of the plan, will probably amount to—

A. Passenger trains in both directions together—

a.	Upon the Hamburg through tracks	200 trains.
	City tracks	200 "
b.	Upon the Blankenese tracks	100 "
c.	Upon the Northern tracks	80 "

B. Freight trains to and from the switchyard at Langenfelde—

a.	Towards Hamburg	40 trains.
b.	Towards Altona Harbor	40 "
c.	Toward Blankenese	10 "

In addition to this, a considerable increase of traffic is certainly to be expected. Under these circumstances, to retain even a part of the above crossings appeared hazardous to the regularity and safety of the traffic. There was, therefore, an arrangement of tracks planned, such as is presented in Plate I. Owing to the great extension of the design, the lengths are drawn to one-half scale compared with the width, and the drawing therefore appears distorted. The course of the several trains is indicated by various kinds of marks.

As may already be seen from the above, it was adhered to as a principle in the project that crossings at grade of two passenger tracks, as well as of a passenger and a freight track, should be avoided. The carrying out of this principle was everywhere successful excepting the point where the freight track, leading from Langenfelde to Bahrenfeld, crosses over into the two Blankenese main tracks. This point lies, however, just at the Bahrenfeld Depot, and these level crossings did not appear hazardous in view of the infrequency of the freight trains—only five in each direction.

For the attainment of the before-mentioned object the preparation of five, in part very comprehensive, structures was necessary (see Nos. 1 to 5, Plate I). Furthermore, the switchyard of Langenfelde had to be placed between the two northern tracks. From the drawing the arrangement of the tracks may be sufficiently understood, and it is only necessary to remark, that in deviation from the usual rule, trains on the city tracks from Structure 5 to Altona Depot, and upon the northward tracks between Structure 1 and the Altona Depot, will run on the left side track.

The location of the side and storage tracks for passenger trains between the through tracks—and, indeed, between the tracks from Hamburg and to the north on one hand, and the tracks from the north and to Hamburg on the other hand—further contributes essentially to the obviation of grade crossings that would occur in hauling and and removing empty trains to and from the six platform tracks, and increases materially the working capacity of the improvement. The difficulty of the project was essentially increased by the fact that all street crossings at grade had also to be abolished, and replaced by over and under crossings.

The project is in course of construction and is about half finished.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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COMMON ROADS, RAILWAYS AND RIVER COMMUNICATIONS IN PORTUGAL.

By FREDERICO AUGUSTO PIMENTAL, Civil Engineer, of Lisbon, Portugal.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

COMMON ROADS.

Common roads or highways are classified under the following heads: First-class or royal roads, second-class or district roads, and third-class or municipal roads. First-class roads connect Lisbon with the chief towns of the districts and with the principal places on the frontier. Second-class roads connect the above named and the cities and principal towns either with each other or with the railway stations and river ports; and lastly, those of the third class join the townships or *concelhos* with each other or with the preceding roads. The continental part of Portugal is divided into administrative districts, and these into townships or *concelhos*.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

The following table shows the total and mean population of each district on the Continent, and its area in square kilometers:

Names of Districts.	Number of townships or *concelhos*.	Area in square kilometers.	Population.	Density of population per square kilometer.
Aveiro	16	2 908.61	290 026	99.71
Beja	14	10 871.28	165 528	15.04
Braga	13	2 738.20	360 151	131.52
Bragança	12	6 669.33	189 592	28.27
Castello Branco	12	6 621.03	208 836	31.54
Coimbra	17	3 883.10	324 330	83.52
Evora	13	7 087.83	121 134	17.09
Faro	15	4 849.95	229 132	47.24
Guarda	14	5 556.63	266 225	47 91
Leiria	12	3 478.15	222 075	63.82
Lisbon	27	7 049.30	613 956	87.11
Portalegre	15	6 431.01	115 546	17.97
Oporto	18	2 292.07	552 865	241.21
Santarem	18	6 861.86	258 888	37.72
Vianna do Castello	10	2 243 44	215 518	96.04
Villa Real	14	4 447.23	239 695	53.89
Vizeu	26	4 922.25	404 203	82.31
	266	88 911.27	4 774 700	53.70

The city of Lisbon has 307 691 inhabitants, and Oporto, 141 924. It was about 1852 that the road system began to have greater development, and since that period to July 30th, 1892, 8 427 km. of royal and district roads, and nearly 2 850 km. of municipal roads, have been constructed.

The length of royal and district roads in the different administrative districts is shown in the table on the next page, in comparison with their area and population.

The length of the first and second class roads in meters is reckoned to be 18 426 791; 7 690 632 m. being first-class, and 10 736 158 m. second-class, roads. The normal width of the first-class roads is 6.6 m., 4.4 m. being for carriage-way and 2.2 m. for bermes; and the width of second-class roads is 6 m., 4 m. being for carriage-way and 2 m. for bermes. These dimensions may be enlarged in the vicinity of great centers or marts, and close to much-frequented railway stations. The maximum gradient allowed for first and second class roads is 5%, and the maximum radius of junction curves, 30 m. The width of third-class or municipal roads is 5 m., 3.5 m. being for carriage-way and 1.5 m. for bermes or footpaths. The maximum slope allowed is 7%, and 10 m. the maximum radius for junction curves.

The cost of construction and maintenance of first and second class roads is defrayed by the State, and to the account of the municipalities belongs that of municipal roads, the State contributing one-third of the amount to be expended, in a strict sense, in their construction. The corporations collect special revenues for municipal roads.

Names of Districts.	Length of Roads In Meters.		
	First and second class roads. Total.	For each square kilometer.	Per 1 000 inhabitants.
Aveiro	537 895	184.90	1 854.60
Beja	364 419	33.50	2 228.48
Braga	610 927	223.10	1 697.00
Bragança	366 698	54.98	1 933.50
Castello Branco	561 093	84.70	2 686.70
Coimbra	639 909	164.79	1 973.00
Evora	413 444	58.33	3 413.11
Faro	363 179	74.80	1 585.10
Guarda	501 598	92.07	1 884.09
Leiria	451 010	129.00	1 296.98
Lisbon	1 294 149	292.50	1 212.40
Portalegre	410 487	63.84	3 552.58
Oporto	670 448	292.50	1 212.40
Santarem	573 442	83.50	2 215.00
Vianna do Castello	388 821	173.30	1 808.40
Villa Real	404 338	80.90	1 684.70
Vizeu	515 447	104.70	1 250.50
	9 067 304	94.78	1 165.01

RAILWAYS.

On December 31st, 1891, there were 2 283.274 km. of working railways, 2 088.653 km. being broad-gauge and 194.621 km. narrow-gauge.

The length of broad-gauge lines under construction was 176.675 km.

Of the length of railways open for traffic, 1 467.960 km. were worked and managed by companies, and 815.314 km. by the State.

The lines worked by companies are divided as follows :

BROAD-GAUGE LINES.

The Royal Company of Portuguese Railways.

	Kilometers.
Lisbon by Elvas to the frontier	275.599
Entroncamento to Oporto	228.873
Carried forward	504.472

	Kilometers.
Brought forward	504.472
Caceres branch line	71.849
Lisbon to Cintra	27.375
Lisbon (Cacem) to Torres Vedras	45.300
Torres to Figueira	151.495
Alfarellos branch line	16.516
Circuit or Circumvallation line	12.856
Lisbon to Cascaes	23.525
Coimbra branch line	1.700
Beira Baixa line	166.000
Total	1 021.088

THE BEIRA ALTA COMPANY.

	Kilometers.
Figueira da Foz to Villar Formoso	252.251

NARROW-GAUGE LINES.

OPORTO TO POVOA AND VILLA NOVA DE FAMALICAO RAILWAY COMPANY.

	Kilometers.
Oporto to Famalicao	57.257

THE BOUGADO AND GUIMARAES RAILWAY COMPANY.

Bougado to Guimaraes	33.135

THE NATIONAL COMPANY.

Foz do Tua to Mirandella	54.679
Vizeu branch line	49.550
Total	104.229

LINES WORKED AND CONSTRUCTED BY THE STATE.

BROAD-GAUGE.

	Kilometers.
Oporto to Valença	131.194
Braga branch line	15.164
Oporto (Ermezinde) to Barca d'Alva	191.766
Custom House branch line	3.916
Barreiro to Pias	195.908
Setubal branch line	12.809
Casa Branca and Extremoz branch line	78.080
Beja to Faro	186.477
Total	815.314

LINES UNDER CONSTRUCTION.

BROAD-GAUGE.

The Royal Company of Portuguese Railways.

	Kilometers.
The Beira Baixa line	45.675

Southern Railways Company.

Vendas Novas to Santarem	71.00
Coimbra to Arganil	60.00

All the roads are single track, with the exception of the railway from Lisbon to Cacem, of that of Cascaes, and of the Eastern line between Lisbon and the Entroncamento at Gollega. The width of the broad-gauge line is 1.67 m. between the inner edges of the rails. The building of Portuguese railways began on September 17th, 1853, and the first section open to traffic was the one between Lisbon and Carregado on the Eastern line.

The technical and economic conditions of the lines worked either by companies or managed by the State are the following:

The Eastern Railway.

This line begins at Lisbon (Caes dos Soldados) and follows along the bank of the Tagus up to Abrantes, where it bends towards Elvas, joining at Badajos the Spanish line. It traverses the administrative districts of Lisbon, Santarem and Portalegre. Its technical conditions, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	183 722.24	66.60
Curves with radius below 400 m	1 026.18	0.40
" " from 400 to 500 m	2 580.34	0.90
" " " 500 to 600 m	11 173.74	4.00
" " " 600 to 700 m	11 451.25	4.10
" " " 700 to 800 m	9 705.19	3.60
" " " 800 to 900 m	7 098.01	2.60
" " " 900 to 1 000 m	7 954.18	2.90
" " above 1 000 m	40 887.87	14.90
Totals	275 599.00	100.00

Grade.	Length in meters.	Percent. of total length.
Level	30 640	11.10
Grades below 0.001	52 900	19.20
" from 0.001 to 0.005	70 500	25.60
" " 0.005 to 0 010	62 259	22.50
" " 0.010 to 0.012	13 400	4.90
" " 0.012 to 0.015	35 800	12.30
" of 0.015	12 100	4.40
Totals	275 599	100.00

The width at formation level in embankment is 5.50 m. and 6.10 m. in cuttings. The road is of double track between Lisbon and the Entroncamento. It has 32 stations, including the one at the junction with the Northern line; that of Abrantes at the junction with the Beira Baixa line, and that of Torre das Vargens on the Caceres embranchment.

The Northern Railway.

The Northern Railway begins at the junction station of the Eastern line, and traverses the administrative districts of Santarem, Leiria, Coimbra, Aveiro and Oporto. Its technical conditions, both in plan and profile, will be found condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	157 862.78	68.97
Curves with radius below 400 m	252.31	0.11
" from 400 to 500 m	408.05	0.19
" " " 500 to 600 m	10 686.36	4.67
" " " 600 to 700 m	9 434.98	4.12
" " " 700 to 800 m	3 471.22	1.51
" " " 800 to 900 m	2 967.78	1.29
" " " 900 to 1 000 m	9 683.91	4.22
" " above 1 000 m	34 106.81	14.92
Total	228 873 20	100.00

Grade.	Length in meters.	Percent. of total length.
Level	25 792.20	11.22
Grades below 0.001	27 704.40	12.10
" from 0.001 to 0.005	68 600.00	29.97
" " 0.005 to 0.010	53 350.00	23.39
" " 0.010 to 0.012	24 500.00	10.70
" " 0.012 to 0.015	14 692.10	6.41
" above 0.015	14 234.50	6.21
Total	228 873.20	100.00

The width at formation level is the same as that of the Eastern Railway. The line has 22 stations, including those of Alfarellos and Pampilhosa, the first at the junction of the Figueira branch line, and the second belonging to the Beira Alta Railway.

The Eastern and Northern railways have been constructed by the Royal Company, and are to be worked for a period of 99 years by the same, the State granting a subvention or 112 500 francs per kilometer for the Eastern, and 135 000 francs for the Northern, line. This line has five tunnels, measuring altogether 1 701.75 m. in length, and among its numerous constructive works is the remarkable bridge Maria Pia over the Douro, with a single arch of 160 m. span and 37.5 rise, its flooring being 61.30 m. above low water mark.

Goods and Passenger Traffic.—The number of passengers conveyed in the year 1890 by this line was 1 676 692. The number of kilograms of goods transported at high speed was 18 398 841, and at low speed, 759 402 879. The trains have third-class carriages.

The general rates are: 0.1102 franc per kilometer for first class, 0.0857 franc per kilometer for second class, and 0.00613 franc per kilometer for third class.

The 343 km. run between Lisbon (Rocio station) and Oporto is performed by the mail trains in 10 hours 45 minutes, and the 272 km. run between Lisbon and Elvas in 10 hours 46 minutes.

The proportion of passengers in the different classes is as follows: 9.07% of first class, 19.44% of second class, and 71.49% of third class.

The gross earnings per kilometer in the year 1890 amounted to 29 630.4 francs, and the coefficient of the working of the line is 34.98 per cent.

The Caceres Branch Line.

The Caceres branch begins at kilometer 174.8 on the Eastern line at Torre das Vargens station, and following the route to the frontier it joins the Caceres and Madrid line. Its whole length is comprised within the administrative district of Portalegre. It was built by the Royal Company without any charge whatever to the State.

The technical conditions of this line, both in plan and profile, are condensed in the tables on the next page.

The width at formation level is 5 m. in embankment and 5.5 m. in

cuttings. It has five stations, including the one at the commencement of the line.

Alignment.	Length in meters.	Percent. of total length.
Straight	27 830.45	38.28
Curves with radius of 300 m	21 794.85	30.30
" " from 300 to 400 m	8 574.50	11.93
" " " 400 to 500 m	9 178.4	12.76
" " " 500 to 600 m	2 817.8	3.80
" " " 600 to 700 m	702.80	0.92
" " " 1 000 m	950.20	1.92
Totals	71 849.00	100.00

Grade.	Length in meters.	Percent. of total length.
Level	18 536.6	25.93
Grades from 0.001 to 0.005	2 320.0	3.22
" " 0.005 to 0.008	8 358.4	11.49
" " 0.008 to 0.010	5 934.0	8.26
" " 0.010 to 0.012	10 518.0	14.63
" " 0.012 to 0.014	8 241.3	11.47
" " 0.014 to 0.015	5 431.0	7.56
" " 0.015 to 0.018	9 062.4	12.61
" " 0.018 to 0.125	3 447.3	4.83
Totals	71 849.0	100.00

Goods and Passenger Traffic.—The passengers conveyed in the year 1890 by this line were 28 123, and the number of kilograms of goods transported were: at high speed, 871 245; at low speed, 45 509 735.

The proportion in the different classes is of 33% for first class, 23% for second class, 44% for third class.

The general rates on this branch line are the same as in force for the Northern and Eastern railways.

Lisbon to Cintra and Torres Vedras, Figueira da Foz and Alfarellos Railway or Western Line.

Lisbon to Cintra.—The line from Lisbon to Cintra begins at Alcantara station, and follows in the direction of Cintra after its junction at Campolide with the City line and at Cacem with the Torres and Figueira Railway.

Its technical conditions are condensed in the following tables:

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	14 135.61	51.64
Curves with radius of 320 m	432.10	1.50
" " " 350 m	2 544.68	9.29
" " " 400 m	2 051.23	7.49
" " " 500 m	3 269.98	11.94
" " " 600 m	1 132.74	4.14
" " " 650 m	598.43	2.18
" " " 800 m. and above	3 210.13	11.82
Totals	27 374.90	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	7 008.90	25.64
Grades from 0.001 to 0.005	1 650.00	5.80
" " 0.005 to 0.010	2 275.00	8.31
" " 0.010 to 0.012	5 145.55	18.79
" " 0.012 to 0.015	3 686.00	13.56
" " 0.015 to 0.018	7 609.45	27.90
Totals	27 374.90	100.00

The width at formation level is 8.70 m. in cuttings and 9.03 m. in embankment. The road is of double track between Lisbon and Cacem and has three tunnels, their total length being 705 m.

Lisbon (Cacem) to Torres Vedras.—This line commences at the Cacem station (kilometer 19 216.0 of the Cintra Railway), its whole length being comprised within the bounds of the Lisbon administrative district. The line was built by the Royal Company without any charge whatever to the State.

Its technical conditions in plan and profile are summarily contained in the following tables:

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	23 629.16	51.94
Curves with radius of 350 m	3 676 99	8.11
" " " 400 m	5 591.33	12.24
" " from 400 to 500 m	5 509.10	12.16
" " " 600 to 700 m	4 564.52	10.62
" " " 800 to 900 m	262.54	0.58
" " above 900 m	2 066.36	4.35
Totals	45 300.00	100 00

GRADE.	Length in meters.	Percent. of total length.
Level	9 376.00	20.73
Grades from 0.000 to 0.005	3 000.00	6.73
" " 0.005 to 0.010	5 857.00	12.72
" " 0.010 to 0.012	3 200.00	7.16
" " 0.012 to 0.015	10 848.00	23.94
" " 0.015 to 0.018	13 019.00	28.72
Totals	45 300.00	100.00

The width at formation level is 5 m. in cuttings and 5.30 m. in embankment. This line has four tunnels measuring 715 m. of total length and eight stations, including the one of Cacem at the junction with the Cintra Railway.

Goods and Passenger Traffic.—The number of passengers conveyed during the year 1890 by the Lisbon, Cintra and Torres Railway amounted to 597 202; the number of kilograms of merchandise transported at high speed being 2 144, and at low speed, 651 030.

The proportion of passengers in the different classes was of 14.9% in first class, 30.5% in second class, 44.6% in third class.

The gross earnings per kilometer were 21 036 francs, the coefficient of the working being 57.12 per cent.

Torres Vedras to Figueira da Foz.—This road begins at the terminus of the Lisbon and Torres line and forms its extension to Figueira. It was constructed by the Royal Company and is to be worked by the same for a period of 99 years, the State allowing 5% for completement of interest and payments of 166 667 francs capital per kilometer, the disbursement of the State never exceeding, however, 2 per cent.

This line is laid across the administrative districts of Lisbon, Leiria and Coimbra. Its technical conditions, both in plan and profile, are condensed in the following tables:

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	102 118.70	67.40
Curves with radius of 350 m	235.19	0.15
" " of 400 m	3 571.25	2.35
" " from 400 to 500 m	17 963.00	11.87
" " " 600 to 700 m	10 698.19	7.08
" " " 800 to 900	4 358.13	2.89
" " " 1 000 and above	12 550.70	8.28
Totals	151 495.16	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	39 480.38	26.06
Grades from 0.005	28 305.00	18.68
" " 0.005 to 0.010	26 355.00	17.38
" " 0.010 to 0.012	12 852.00	8.48
" " 0 012 to 0.015	43 702.78	28.84
" " 0.015 to 0.018	800.00	0.56
Totals	151 495.16	100.00

The width at formation level is the same as that of the Lisbon line (Cacem-Torres). It has 23 stations, including the one of Torres at its commencement.

Alfarellos Branch Line.—This branch connects the Northern line at kilometer 200, counting from Santa Apolonia station at Lisbon, with the line of Figueira at Amieira station. It was constructed and is worked on the same terms as the line of Torres to Figueira.

The technical conditions of this railroad in plan and profile are condensed in the following tables :

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	8 037.14	48.66
Curves with radius of 300 m	214.67	1.30
" " 400 m	610.63	3.69
" " 500 m	3 411.08	20.65
" " 600 m	2 812.44	17.02
" " 800 m	1 146.32	6.92
" " 1 500 m	283.62	1.76
Totals	16 515.90	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	10 264.90	62.15
Grades of 0.005	5 581.00	33.80
" 0.015	670.00	4.05
Totals	16 515.90	100.00

The width at formation level is the same as that of the line from Torres to Figueira. It has three stations, including those of Alfarellos and Amieira.

The passengers conveyed in the year 1890 by the line of Torres to Figueira and by the Alfarellos branch were 285 507, and the number of kilograms of goods transported at full speed amounted to 141 200.

The proportion of passengers in the different classes was of 8.1% in first class, 19.4% in second class, and 72.5% in third class.

The general rates applied to the Lisbon, Cintra, Torres, Figueira and Alfarellos railroads are, 0.1102 franc per kilometer for first class; 0.0857 franc per kilometer for second class, and 0.00613 franc per kilometer for third class.

The gross earnings in 1890 amounted to 10 381.3 francs per kilometer, the coefficient of the working being 68.12 per cent.

The City and Circuit Lines.

The Circuit line connects the Eastern and the Cintra railways with the Rocio station within the city of Lisbon. Its total length is 12 856 m.

The Circuit line, or, as it is more commonly called, the Circumvallation line, has a tunnel 180.5 m. in length, and the City line another, 2 600 m. in length. Both lines were constructed by the Royal Company without any charge to the State.

The Cascaes Railway.

The Cascaes Railway begins at Alcantara station in Lisbon, and, following along the right bank of the Tagus, puts in easy communication with the capital the watering-places bordering on the river and those of Estoril and Cascaes at its terminus. It was constructed by the Royal Company without any charge to the State. This road is of double track between Pedrouços and Cascaes.

Its technical conditions in plan and profile are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	15 601.68	66.30
Curves with radius from 200 to 300 m	214.68	0.90
" " " 300 to 400 m	4 518.34	19.20
" " " 400 to 600 m	2 765.41	11.70
" " above 600 m	425.23	1.90
Totals	23 525.34	100.00

Grade.	Length in meters.	Percent. of total length.
Level	14 437.43	61.30
Grade from 0.000 to 0.005	2 708.61	11.50
" " 0.005 to 0.010	1 628.00	6 90
" " 0.010 to 0.014	4 751.30	20.30
Totals	23 525 34	100.00

This railroad has 14 stations, including that of departure, and its general rates are collected by sections, the line being divided into three.

Rates: first class, 0.888 franc; second class, 0.444 franc; third class, 0.277 franc.

Passenger Traffic.—The number of passengers conveyed by the line amounted to 615 592 in the following proportions: 14 339 first-class passengers, or 2.32%; 285 564 second-class passengers, or 46.38%; 315 689 third-class passengers, or 51.30 per cent.

The Beira Baixa Railway.

This line commences at the station of Abrantes, on the Eastern railroad, 31.33 m. above the mean level of the sea, running thence along the right bank of the Tagus up to Portas de Rodao, where it attains the altitude of 107.211 m. above the said level. From this point it pursues its course by the neighborhoods of Castello Branco and Covilha to the vicinity of Guarda, where it ends at the altitude of 811.567 m. in the Beira Alta Railway, after crossing the administrative districts of Santarem, Castello Branco and Guarda.

It was constructed by the Royal Company, the State allowing the same company 5.5% for interest and payment of cost, which, according to the contract, was at the rate of 198 888 francs per kilometer.

The technical conditions of this railway, both in plan and profile, may be condensed in the tables on the next page.

The width at formation level on the upper surface of the embankments is 5.30 m. and of 5 m. in the cuttings. Besides numerous constructive works, this railway has 10 tunnels, the aggregate length of which is 1 981.50 m. The stations are 24 in number, including that of Abrantes, which serves at the same time the Eastern Railway, and the Guarda station, which belongs in common to the Beira Alta line.

Alignment.	Length in meters.	Percent. of total length.
Straight	135 343.64	63.93
Curves with radius of 300 m	32 915.43	15.55
" " from 300 to 400 m	24 346.55	11.50
" " " 400 to 600 m	14 740.42	6.96
" " above 600 m	4 329.36	2.06
Totals	211 675.40	100.00

Grade.	Length in meters.	Percent. of total length.
Level	89 085.83	42.08
Grades from 0.005	14 868.00	7 02
" " 0.005 to 0.010	13 845.00	6.51
" " 0.010 to 0.015	23 968.00	11.32
" " 0.015 to 0.018	69 908.57	33.07
Totals	211 675.40	100.00

This railway was still in course of building in 1890, and on September 7th, 1891, 166 km. were open to circulation between Abrantes and Covilha.

Besides the roads described the Royal Company has at its charge the working of a broad-gauge branch connecting the Coimbra station with the heart of the town, and which is destined to serve as terminus to the Arganil line, at present under construction. This branch is 1 700 m. in length.

The Southern and South-Eastern Railways.

The Southern and South-eastern lines have both their common origin at Barreiro, on the left bank of the Tagus. The main line leads to the Algarve, its terminus being at Faro, the capital of the district bearing this name. A branch extends to the town of Setubal, and another to Extremoz, which passes near Evora, extending from thence to Beja and Pias. These railways cross the administrative districts of Lisbon, Evora, Beja and Faro. The main line and its branches are owned and managed by the State. The width of the track is 1.67 m. between the inner edges of the rails.

The technical conditions of its various parts, both in plan and profile, are condensed in the following tables:

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	148 465.37	76.24
Curves with radius from 300 to 350 m.	1 391.72	0.71
" " " 350 to 400 m.	4 465.84	2.26
" " " 400 to 600 m.	3 963 22	2.02
" " " 600 to 800 m.	3 341.75	1.55
" " " 800 to 1 000 m.	214.00	0.01
" " above 1 000 m.	34 066.64	17.21
Totals.	195 908.54	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	31 679.09	16.13
Grades from 0 005	51 542.50	26.39
" " 0.005 to 0.010	94 996.05	48.49
" " 0.010 to 0 015	15 033.41	7.67
" " 0.015 to 0.016	2 657.49	1.32
Totals.	195 908.54	100.00

THE SETUBAL BRANCH LINE.

This branch begins at Pinhal Novo station and ends at Setubal, after a course of 12 809.60 m. Its length in straight alignment is 8 538.96 m., and 4 270.64 m. in curved alignments, which is equivalent to 66.6% of the first and to 33.4% of the second, for its whole extent.

The technical conditions of the profile may be seen in the following table:

GRADE.	Length in meters.	Percent. of total length.
Straight	557.30	4.35
Grades from 0.005	6 349.64	49.72
" " 0.005 to 0,010	5 902.66	45.93
Totals.	12 809.60	100.00

The Casa Branca and Extremoz Branch Line.

This line begins at Casa Branca station and ends at the town of Extremoz, after passing close to the city of Evora. Its technical conditions, both of plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	47 227.56	60.48
Curves with radius of 300 m	1 263.60	1.61
" " of 350 m	475.46	0 51
" " from 400 to 450 m.	13 788.63	17.65
" " " 600 to 750 m.	3 623 87	4.64
" " " 750 to 800 m.	1 948.73	2.49
" " above 1 000	9 751.95	12.62
Totals	78 079.80	100.00

Grade.	Length in meters.	Percent. of total length.
Level	14 926.70	19.11
Grades from 0 005	16 413.60	21.02
" " 0.005 to 0 010	22 716.86	29.09
" " 0.010 to 0 015	24 022.64	30.78
Totals	78 079.80	100.00

Beja and Faro Railway.

It is at Beja station that the line of the Algarve bends towards that province, ending at Faro after a run of 186 477.32 m. In its first section from Beja to Casevel, 46 682 m. in length, it has 16 774 m. in curved alignments, or 35.98% of its whole extent.

The technical conditions of this line in profile are condensed in the following tables:

Grade.	Length in meters.	Percent. of total length.
Level	5 084.0	10.90
Grades from 0.005	10 357.0	22.22
" " 0.005 to 0.010	17 423.0	37.36
" " 0.010 to 0,015	10 973.0	23.53
" " 0.015 to 0 018	2 791.0	5.99
Totals	46 628.0	100.00

The Casevel and Faro Section.

The technical conditions of this section of the main line, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	85 073.35	60.82
Curves with radius of 300 m	12 877.51	9.21
" " from 300 to 400 m	16 001.43	11.44
" " " 400 to 600 m	13 062.73	9.34
" " above 600 m	12 834.30	9.19
Totals	139 849.32	100.00

Grade.	Length in meters.	Percent. of total length.
Level	26 485.75	18.94
Grades from 0.005	16 363.50	11.71
" " 0.005 to 0.010	22 883.63	16.38
" " 0.010 to 0.018	74 116.44	52.97
Totals	139 849.32	100.00

The width at formation level in embankment measures 5.30 m. and 6.20 m. in cuttings. It has 45 stations, of which 32 belong to the main line from Barreiro to Faro, 2 to the Extremoz branch, 7 to that of Setubal, and 4 to the extension from Beja to Pias.

Goods and Passenger Traffic.—The number of passengers conveyed by this line during the year 1890 was of 340 915, and the amount of metrical tons of merchandise transported at low speed 158 404.

The run between Barreiro and Faro for a length of 340 km. is accomplished by mail trains in 12 hours 25 minutes. The general passenger fares are: 0.105 franc per kilometer for first class, 0.0815 franc per kilometer for second class, and 0.059 franc per kilometer for third class.

The gross earnings for 1890 amounted to 7.973 francs per kilometer and the coefficient of the working was 62.08 per cent.

The Minho Railway.

The Minho Railway begins at Oporto, where it is joined by the Northern line, and follows its course through the province of Minho,

serving its cities and principal towns, such as Braga, Barcellos, Vianna up to Valença, where it joins, by means of the international bridge over the river of the same name, with the Spanish line of Orense and Vigo. It is 131 194.52 m. in length. The city of Braga is reached by a branch line 15 163.71 m. in length.

This railway was built and is worked directly by the State. Its course lies through the districts of Oporto, Braga and Vianna do Castello.

The technical conditions, both in plan and profile, either of the main line or of the Braga branch, may be found condensed in the following tables :

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	88 481.07	67.44
Curves with radius from 300 to 400 m	7 502.48	5.71
" " " 400 to 500 m	8 765.95	6.67
" " " 500 to 600 m	4 729.31	3.60
" " above 600 m	21 715.71	16.58
Totals	131 194.52	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	38 726.02	29.51
Grades from 0.005	18 714 88	14.26
" " 0.005 to 0.010	14 879.06	11.34
" " 0.010 to 0.012	12 388.21	9.44
" " 0.012 to 0.015	46 487.35	35.45
Total	131 194.52	100.00

THE BRAGA BRANCH LINE.

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	8 905.36	58.72
Curves with radius of 400 m	1 238.61	8.16
" " " 400 to 500 m	822.04	5.42
" " " 500 to 600 m	733.40	4.83
" " above 600 m	3 464.30	22.87
Totals	15 163.71	100.00

Grade.	Length in meters.	Percent. of total length.
Level	3 872.24	25.53
Grades from 0.005 to 0.010	2 641.97	17.42
" " 0.010 to 0.015	6 604.43	43.55
" " 0.015 to 0.016	2 005 07	13.50
Totals	15 123.71	100.00

The width at formation level in embankment is 5.30 m. and 4.50 m. in cuttings. This line has, besides some important constructive works, six tunnels, the aggregate length of which is 2 174.90 m.

Goods and Passenger Traffic.—During the year 1890, 554 387 passengers were conveyed by this line, and the amount of goods transported at low speed was of 100 824.429 metrical tons.

The proportion of passengers in the different classes were as follows: 8.28% of first class, 17.57% of second class, and 74.15% of third class. There are 30 stations on the Oporto and Valença route, and five on the Braga branch, including one common to the main line. The general rates for passengers were: 0.105 franc per kilometer for first class, 0.0813 franc per kilometer for second class, and 0.059 franc per kilometer for third class.

The run on this line is accomplished by mail trains in 5 hours 18 minutes.

The Douro Railway.

The Douro line begins at the station of Ermezinde, on the Minho railroad, distant 8 426 m. from the city of Oporto, and crossing the province of Minho, enters afterwards in the Douro valley, through which it pursues its course to the border of the kingdom, joining there the Salamanca Railway by means of a bridge over the River Agueda. Its course lies through the Oporto, Villa Real and Bragança districts, bordering also on those of Vizeu and Guarda. It was constructed and is worked directly by the State.

Better to appreciate the technical conditions of this line, we shall divide it into two sections, the first from its commencement to Pinhao station on the right bank of the Douro, and the second from this point to its terminus on the frontier.

SECTION OF THE DOURO RAILWAY FROM ERMEZINDE TO PINHAO.

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	69 266.71	58.25
Curves with radius of 250 m	2 120.79	1.78
" " from 250 to 400 m	22 444.27	18.87
" " " 400 to 800 m	18 913.31	15.82
" " above 800 m	6.171.61	5.28
Totals	118 916.69	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	40 579.23	34.12
Grades from 0 010	27 306.02	22.96
" " 0.010 to 0.014	20 404.59	17.20
" " 0.014 to 0.016	30 626.85	25.72
Totals	118 916.69	100.00

SECTION BETWEEN PINHAO AND BARCA D'ALVA.

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	42 327.399	58.24
Curves with radius of 250 m	1 659.74	2.28
" " from 250 to 300 m	14 973.69	20.55
" " " 300 to 400 m	4 803.08	6.59
" " " 400 to 500 m	3 965.65	5.44
" " " 500 to 600 m	1 894 97	2.60
" " above 600 m	3 224.84	4.30
Totals	72 849.369	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	30 418,829	41.75
Grades from 0.005	36 696.210	50.37
" 0.005 to 0.010	2 741.00	3.76
" 0.010 to 0.015	2 993.33	4.12
Totals	72 849.369	100.00

The width at formation level is of 5.3 m. in embankment and 5 m. in cuttings.

Besides numerous constructive works, this line has 23 tunnels, the total length of which is 6 914 m.

Goods and Passenger Traffic.—The number of passengers conveyed by this line during the year 1890 was of 345 902, and the number of tons of merchandise at low speed 137 120.950.

The gross earnings of the Minho and Douro railways were 14 396.6 francs per kilometer, and the coefficient of the working 55 per cent.

The number of stations is 36. The general rates are the same as those in force on the Minho line. As a dependence of the Minho and Douro lines, the State constructed a branch line connecting the Oporto station with the custom house 3 915.92 m. in length.

This branch line has three tunnels, the total length of which is 1 377.36 m.

The Beira Alta Railway.

This line begins at the town of Figueira, joining the northern line at the Pampilhosa station, and its terminus is at Villar Formoso on the Spanish frontier, where it effects its junction with the Salamanca railway. The road crosses the mountain of Bussaco, where it gains the altitude of 215 m. above the level of the sea, passing in the vicinity of the city of Guarda, where the altitude attained is of 809 m. Besides serving a large tract of land, this line constitutes the shortest route from the central part of Portugal to the north of Spain. This railway was constructed and is worked by the Beira Alta Company, the State granting a kilometric subvention of 127 777 francs for the length of 202 207.14 m. from Pampilhosa to the frontier, the section from that point to Figueira, 50 044.66 m. in length, being constructed without any charge to the State. It crosses the administrative districts of Coimbra, Aveiro, Vianna and Guarda.

The technical conditions of this line, both in plan and profile, are condensed in the following tables :

Alignment.	Length in meters.	Percent. of total length.
Straight	143 896.73	57.04
Curves with radius of 350 m	22 418.64	8.89
" " of 400 m	15 499.14	6.15
" " from 400 to 500 m	23 027.48	9.13
" " " 500 to 650 m	11 960.08	4.73
" " " 650 to 900 m	10 175.42	4.04
" " above 900 m	25 274.31	10.02
Totals	252 251.80	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	66 767.39	26.46
Grades from 0.005	21 175.00	8.40
" 0.005 to 0.010	33 598.09	13.34
" 0.010 to 0.012	20 796.92	8.24
" 0.012 to 0.014	42 376.00	16.79
" 0.014 to 0.015	67 538.40	26.77
Totals	252 251.80	100.00

The width at formation level is 5.40 m. in embankment and 5 m. in cuttings. There are many and most important constructive works on this line and 13 tunnels with the aggregate length of 3 822.62 m. The stations are 27 in number, including that of Pampilhosa which is common to the Northern line.

Goods and Passenger Traffic.—The number of passengers conveyed in the year 1890 was 227 216, and the number of tons of merchandise at low speed, 102 875.

The proportion of passengers in the different classes was of 6.92% for first class, 16.53% for second class, and 76.44% for third class.

The gross earnings in 1890 amounted to 8 197 francs and the coefficient of the working was 46.2 per cent.

The run of trains between Figueira and Villar Formoso is accomplished in 11 hours, including the stoppage of 45 minutes at Pampilhosa.

NARROW-GAUGE RAILWAYS.

LINE FROM OPORTO BY POVOA DE VARZIM TO VILLA NOVA DE FAMALICAO.

This line, beginning at Oporto, follows by the seaside to Povoa de Varzim, where it bends towards Villa Nova de Famalicao, joining there the Minho Railway. Its technical conditions, both in plan and profile, are condensed in the following tables, the line having been built and being worked without any charge to the State.

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	46 136.98	80.57
Curves with radius of 100 m.	151.80	0.26
" " from 100 to 200 m.	1 737.00	3.03
" " " 200 to 300 m.	4 575.58	8.00
" " " 300 to 400 m.	2 448.00	4.26
" " " 400 to 500 m.	1 475.71	2.57
" " above 500 m.	750.15	1.31
Totals	57275.22	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	13 644.58	23.82
Grades from 0.005	4 310.26	7.53
" " 0.005 to 0.010	8 617.08	15.04
" " 0.010 to 0.015	7 912.90	13.83
" " 0.015 to 0.238	22 790.40	39.78
Totals	57 275.22	100.00

The width of the line of way is 0.90 m. between the inner edges of the rails, the width at formation level in embankment being 3.50 m. and 4 m. in cuttings. This railroad has 17 stations.

Goods and Passenger Traffic.—The number of passengers conveyed by this line during the year 1890 was 351 286, and the tons of merchandise transported at low speed were 18 880. The gross earnings in the same period amounted to 7 870 francs per kilometer, the coefficient of the workings being 58.91. The general rates are 0.15 franc per kilometer for first class and 0.088 franc per kilometer for second class.

THE BOUGADO AND GUIMARAES RAILWAY.

This line begins at Trofa station, on the Minho Railway, and, following by the valley of the River Ave, serves the town of Santo Thyrso and the watering-place of Vizella, bending thence towards Guimaraes, where it ends. It was constructed and is worked by the Bougado Company without any charge to the State.

Its technical conditions are condensed in the following tables:

ALIGNMENT.	Length in meters.	Percent. of total length.
Straight	18 397.10	55.52
Curves with radius of 200 m	6 096.36	18.39
" " from 200 to 300 m	2 653.73	8.00
" " " 300 to 500 m	3 511.64	10.60
" " above 500 m	2 476.57	7.49
Totals	33 135.40	100.00

GRADE.	Length in meters.	Percent. of total length.
Level	6 419.06	19.37
Grades from 0.005	6 455.49	19.48
" " 0.005 to 0.010	8 595.53	25.95
" " 0.010 to 0.015	4 587.54	13.84
" " 0.015 to 0.019	7 077.78	21.36
Totals	33 135.40	100.00

The width of the line of way is 1 m., and that at formation level in cuttings 3.60 m. It has 14 stations.

Goods and Passenger Traffic.—In the year 1890 the number of passengers conveyed by this line was 177 792, and the number of tons of merchandise transported at low speed amounted to 364 631. The general rates are 0.116 franc per kilometer for first class and 0.064 franc per kilometer for second class. The gross kilometric earnings were 9 684.5 francs, and the coefficient of the workings 4.95 per cent.

The Foz do Tua and Mirandella Railway.

This line begins at Fos do Tua station on the Douro Railway, and, following its course by the left bank of the River Tua, ends at Mirandella, after a run of 54 699.64 m. It was built by the National Company (*Companhia nacional*), the Government allowing a guarantee of 5.5% on 109 401 francs, kilometric cost calculated.

The technical conditions, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	34 381.72	62.89
Curves with radius of 150 m	2 023.22	3.74
" " from 150 to 200 m	8 703.25	16.09
" " " 200 to 250 m	2 917 84	5.39
" " " 250 to 300 m	3 369.73	6.03
" " " 300 to 400 m	1 670.78	3.09
" " above 400 m	1 613.21	2.77
Totals	54 679.75	100.00

Grade.	Length in meters.	Percent. of total length.
Level	26 382.65	48.24
Grades from 0.005	12 782.58	23.37
" " 0.005 to 0.010	7 700.01	14.12
" " 0.010 to 0.015	3 813.05	7.00
" " 0.015 to 0.0175	4 001.46	7.27
Totals	54 679 75	100.00

The width of the line of way is 1 m. between the inner edges of the rails, and that at formation level 3.50 m. in embankment and

4.30 m. in cuttings. Besides numerous constructive works, there are six tunnels, the aggregate length of which is 541.75 m.

It has 12 stations.

Goods and Passenger Traffic.—The number of passengers conveyed in the year 1890 was of 33 581, and the amount of goods traffic, 17 327 463 kg.

The proportion of passengers was: For first class, 8%; for second class, 13%; for third class, 79 per cent. The general rates are: 0.105 franc per kilometer for first class; 0.0888 franc per kilometer for second class. The gross earnings per kilometer were, in 1890, 3 888 francs, and the coefficient of the working, 85 per cent.

The Vizeu Branch Line.

This branch line commences at Santa Comba station, on the Beira Alta line, and ends at Vizeu, its length being 49 550.23 m. It was constructed and is worked by the National Company, the Government giving a guarantee of 5.5% for interest and payments of capital, which is of 127 111 francs per kilometer.

The technical conditions of this line, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	29 226 23	58.98
Curve with radius in 150 m.	977.1	1 97
" " from 150 to 200 m.	11 884.1	23.98
" " " 200 to 300 m.	5 515.79	11.13
" " " 300 to 400 m.	756.46	1.52
" " above 400 m.	1 190.55	2.42
Totals	49 550.23	100.00

Grade.	Length in meters.	Percent. of total length.
Level	14 421.11	29.10
Grades from 0.010	3 033.71	6.12
" " 0.010 to 0.012	3 150.80	6.35
" " 0.012 to 0.015	12 999.21	26.11
" " 0.015 to 0.018	15 945.40	32.32
Totals	49 550.23	100 00

The width of the line of way is 1 m. between the inner edges of the rails. The width at formation level in embankment is 4 m., and

4.30 m. in cuttings. This line has 12 stations, including the one of Santa Comba, on the Beira Alta Railway. The general rates are the same as those in force on the Mirandella line.

NAVIGABLE WAYS.

Besides highways and railways, the country has some navigable rivers, the following being the most important :

	Kilometers.
Minho, navigable for the length of	51
Lima, navigable for the length of	38
Douro, navigable for the length of	200
Vouga and Aveiro estuary	80
Mondego	124
Tagus	265
Sado	75
Mira	25
Portimao	20
Guadiana	70
Azambuja, Benavente and Salvaterra canals	42
Total	990

Influence of Means of Communication in the Economic Development of the Country.—Considering that the means of communication are the most prominent factors in the economic existence of nations, it was thought advisable to give some statistical data, with the purpose of showing what has been the influence exercised in the country by such means on comparing the years 1851 and 1890.

Maritime Trade, 1851—

Number of vessels which entered the ports of the Continent carrying freight or in ballast	7 395
Vessels cleared	7 830
Total	15 225

	Tons.
Tonnage of vessels entered	500 671
Tonnage of vessels cleared	542 040
Total	1 042 711

1890.

	Tons.
Number of steam vessels entered carrying freight, 2 728	3 526 383
Steam vessels entered in ballast, 782	1 065 999
Number of sailing vessels entered carrying freight, 1 139	239 813
Sailing vessels entered in ballast, 1 126	62 175
Number of steam vessels cleared carrying freight, 2 650	3 591 366
Steam vessels cleared in ballast, 840	982 144
Number of sailing vessels cleared carrying freight, 1 670	219 341
Sailing vessels cleared in ballast, 819	84 290

Commercial Trade, 1851—

	Francs.
Importation	76 384 650
Exportation	45 713 758
Re-exportation	13 624 234

1890.

Importation	326 876 666
Exportation	178 207 222
Re-exportation	38 535 555
Transit	23 126 111

Public Revenue—

Direct and indirect taxation, 1851	57 111 112
Direct and indirect taxation, 1890	208 805 556

The country continues contributing to its economic development, by giving impulse to the enlargement of the common road and railway systems, and by improving its seaports and other navigable means of transportation.

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TRANSACTIONS.

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THE RAILWAY SYSTEM OF NEW SOUTH WALES.

By THOMAS FLETCHER BIRRELL, Civil Engineer, Newcastle, New South Wales.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Railways and rivers are the two great channels of inland intercommunication available for a people's enterprise. Some countries are, fortunately for themselves, well favored by the endowment of Nature with one of these aids of development. Australia has not been so fortunate. Our water-courses, with the exception of a few, are neither navigable nor large, and even such as we have are only available under certain circumstances. It is some evidence of our enterprise and determination as a people that, since the sod of the first railway was turned in Australia, a little over 40 years ago, we have never relaxed in our persistent efforts to link all parts of the eastern side of the continent together with iron bands. As the beginnings of coloni-

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

zation had its rise in New South Wales, so of course had the Australian system, and it is important to notice that the beginning was quite in conformity with English ideas.

Nearly all our railways are public property, but they began in an attempt at private enterprise. The change has not been due to any economical theorizing, but to a compulsion of circumstances. The colonists were not rich enough for the work, and English capitalists were not at that time awake to the opportunity, and what private enterprise began drifted unavoidably into the hands of the Government. Our railway policy has been made for us rather than by us.

Sixteen years after the opening of the first railway line in England, a public meeting was called in Sydney to discuss the question of railway communication. The idea was well received, and a committee appointed to inquire into the railway question and the cost of constructing an experimental line; and it brought up a report to the effect that a line could be laid from Sydney to Goulburn at a cost of about £6 000 per mile, to yield a profit of 8 per cent. Early in 1848 the survey of the proposed line was completed. A petition was drawn up and presented to the Legislative Council of New South Wales, which referred it to a select committee. On the report of this committee, resolutions were passed by the Council averring that the time was ripe for the inception of a scheme of railway enterprise. Up to this time there had apparently been no idea of the interference by the State in the work of construction, and so far was this from the thought of the committee that a recommendation was appended to its report, that the Government should offer some premium for the encouragement of private enterprise. In November, a provisional committee was appointed and a prospectus issued setting forth the scope of the proposed "Sydney Tramroad and Railway Company" with a capital of £100 000 and interest guaranteed by the Government for 10 years at the rate of 5 per cent. The scrip of the company was promptly taken up, although its aim met with a certain amount of opposition, and some difficulty was at first experienced in galvanizing the public mind into a practical interest in what was then so novel an enterprise. When the first general meeting of shareholders was called in November, 1849, it was found that the affairs of the company were in fair working order. By December a survey had been made to Parramatta and Liverpool, and in January of the next year the directors in

their first report were able to congratulate the shareholders on the prospects of the enterprise in which they were engaged. On July 3d, 1850, the Sydney Railway Company invited the then Governor, Sir Charles Augustus Fitzroy, to witness at Redfern the turning of the first sod of the great railway system of the Australian Continent by the hands of his daughter, the Hon. Mrs. Keith Stuart, in the presence of an enthusiastic concourse of spectators. This was a brilliant commencement. But the company soon found that the heavy drain upon its resources and the necessarily unproductive expenses they were daily incurring began to seriously discourage the shareholders and the public, and very soon they complained that the support of the Government was the only thing that continued to hold the nascent enterprise together. The first contract let was from Rookwood towards Sydney, and the work went on until the gold discovery and the rush of population to the gold fields, with the consequent rise in the price of labor and materials, compelled the company to release the contractors from their obligations.

Another contract was let to carry the work to Ashfield, and thence to Parramatta; 500 navvies were imported, and an additional State loan of £150 000 obtained, with the provision that the Government had power to name one-half of the directors, who had hitherto been elected by the shareholders. This was the first step towards the Government taking the enterprise into its own hands. In January, 1854, the directors announced at a meeting that the cost of the line to Parramatta would exceed the original estimate, owing to the price of labor and material, from £218 240, as estimated in 1852, to £320 000, besides £97 000 for Darling Harbor Works. The capital was increased by £100 000, and another loan of £150 000 was obtained from the State on the same conditions as before. By January of the next year the estimate for the Parramatta line had risen to £500 000, and the shareholders were convinced at last that the prospects of profit on their courageous enterprise had finally disappeared.

In 1853 another movement was initiated to carry a railway line from Newcastle to Maitland, a provisional committee being formed and a capital of £100 000 subscribed immediately. In the course of 12 months, however, this company also found the work beyond its powers, and the inevitable result came to pass in the taking over of the affairs of both companies by the Government of New South Wales

in the year 1854. More money and renewed vigor were put into the enterprise under State management, and in September, 1855, five years after the first sod was turned, and nine years after the railway project was mooted, the line from Sydney to Parramatta was declared open for traffic, and the Government Railway System of New South Wales practically inaugurated at last.

But, although the railway system had its inception in New South Wales, it was in Victoria that the first line was open for actual traffic. The line from Melbourne to Sandridge was not commenced until January, 1853. It was constructed by a private company, and in September, 1854, the line was opened. The first section of the South Australian Railway was from Adelaide to Gawler, which was opened in October, 1857, the distance being 25 miles.

In New Zealand the first railway line thrown open was at Lyttleton (Canterbury District) in December, 1863. Queensland followed on July 31st, 1865, with a line from Toowoombah to Ipswich. Tasmania opened its first section on August 19th, 1869, and the first sod of the West Australian Railway was turned by Governor Weld on November 22d, 1874. The progress in all the colonies has been in every way wonderful, when the sparseness of the population and their resources are taken into consideration. In New South Wales, after the opening of the first short line, the work of railway construction languished for at least 20 years, though only three were allowed to pass without at least some progress being made. These exceptions were the years 1859, 1865, 1866. When two decades had passed, only 437 miles of railway were open in New South Wales, and at the end of 1892 the total length of railway lines in the Colony was 2 359 miles. To this must be added the private line between Moama and Deniliquin, connecting with the traffic from Echuca. The cost of Government lines up to 1893 amounted to over £30 000 000.

The routes are known as the Great Northern, Great Western and Great Southern lines. The first, which for many years had its termination at Newcastle, has now been connected with Sydney, and one of the great works is the bridge over the Hawkesbury River. (This bridge was started in September, 1886, and finished in April, 1889, and cost £400 000. The contractors were the Union Bridge Company of New York.) This line runs through the Newcastle coal district, the agricultural valley of the Hunter River, the rich pastoral country

of New England, connecting with the line to Brisbane on reaching the Queensland border.

The Great Western line passes over that marvel of engineering skill known as the Zig Zag, and passes on by Bathurst and Dubbo to Bourke.

The Great Southern line branches from the junction at Granville, and traverses the southern districts through Goulburn and Wagga Wagga and other principal towns on the route to Albury, where a junction is effected with the Victorian line to Melbourne. The connection of the two chief cities, the most important feat in railway construction in Australia, was finally effected by a bridge over the River Murray at Wodonga in 1883. Besides these main lines there are many branch lines.

In New South Wales the standard gauge is 4 ft. 8½ ins.; in Queensland, 3 ft. 6 ins., and in Victoria, 5 ft. 3 ins. On both the New South Wales frontiers there is therefore a break of gauge.

It is now proposed to consider the railway system of New South Wales, and to compare it briefly with the railway systems of England and America.

The Road.—It would be impossible, in a paper like the present, to go into all the details of modern railway construction, so it is proposed to consider one or two points, and then deal somewhat fully with the various forms of permanent way. One matter which has been too often overlooked by engineers, when constructing lines with sharp curves, is the question of easing off the junction of the straight and curved portions of railways, and the junction of reversed curves by a gradual increase of curvatures. Engineers are fully alive to the advantages of easing of curves, and the custom of introducing transition curves is fast becoming universal. The disagreeable "lurch" which is felt on entering sharp curves is only too well known to those who travel on lines like those of New South Wales. The railways of this colony are most exceptional in their character, having been constructed with an enormous proportion of steep gradients, the worst grades being on the trunk lines and so situated that the whole volume of traffic has to pass over them.

The difficulties surrounding the working of this colony's railways, having more than 2 000 miles of single line and exceptionally sharp curves—and the steepest grades being also on the main lines—will

be readily understood when it is said that there are 629 miles of grades, varying from 1 in 30 to 1 in 75 in the following proportions:

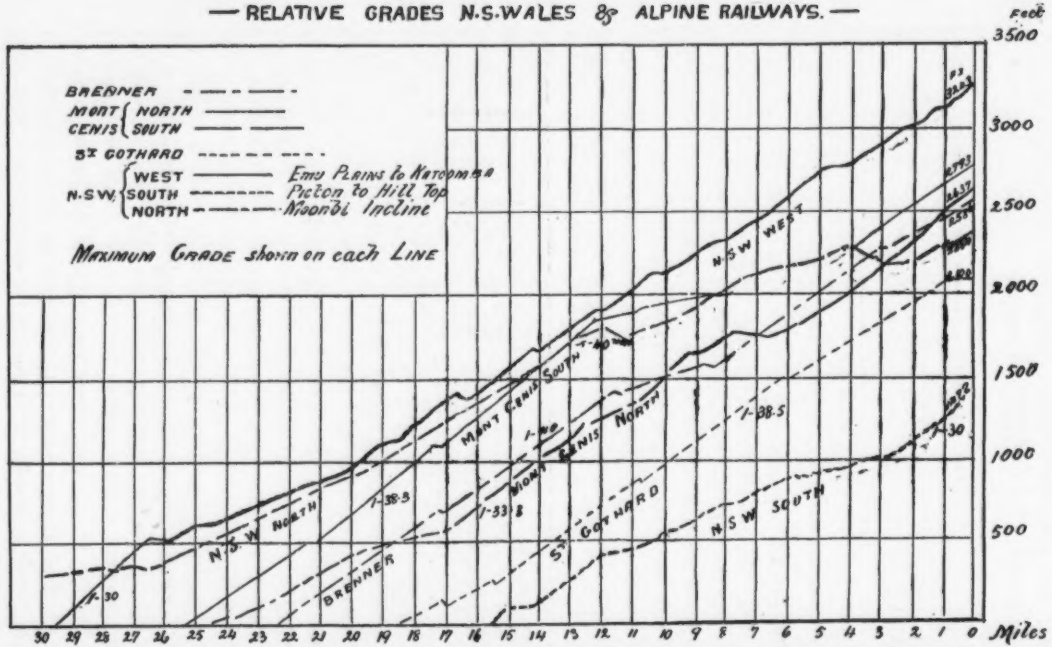
Gradient.	As originally constructed.		Total.		As improved by deviations.		Total.	
	Miles.	Chains.	Miles.	Chains.	Miles.	Chains.	Miles.	Chains.
1 in 30 to 1 in 33.....	25	20	....	....	24	54	189	79
1 in 34 to 1 in 40.....	165	25	190	45	165	25	373	8
1 in 41 to 1 in 50.....	183	60	374	25	183	9	482	14
1 in 51 to 1 in 60.....	112	12	486	37	109	6	628	74
1 in 61 to 1 in 75.....	144	59	631	16	146	60		
	631	16			628	74		

The Great Western line, for instance, is more difficult to work than any of the Alpine railways, the ruling grade (see Fig. 1), radius of curve and frequent loss of elevation which has to be regained being all against the railways of this colony. The following table will illustrate clearly the various lines in question :

Railway.	Length of incline. Miles.	Rise. Feet.	Maximum grade, ascending.	Sharpest curve. Chains.
Brenner.....	22.25	2 586	1 in 40	14.16
Mont Cenis, North.....	24.75	2 637	1 in 33	17.
Mont Cenis, South.....	25.26	2 793	1 in 33	24.
St. Gothard.....	18.5	2 100	1 in 38	14.50
New South Wales, West.....	29.5	3 248	1 in 30	8.
" " South.....	15.5	1 477	1 in 30	16.
" " North.....	30.	2 105	1 in 40	12.

Lurching is principally caused by the fact that it is necessary to work up the superelevation of the outer rail on the straight portion of the road before the curve is reached; consequently, the wheels slide down to the low side, and the flanges rub hard on the low rail immediately before entering the curve, and in taking the curve the flange on the low-side leading wheels suddenly leaves the low rail, and the flange on the high side strikes the high rail, causing the carriage to lurch.

With a properly laid out transition curve the radius is infinity at the point of inflection, and decreases until at the point where it joins the circle the radius of the transition curve is equal to that of the circle; therefore the superelevation can be gradually worked up from the point of inflection, and there will be no tendency for the flanges of the leading wheels to take the low rail, as is the case when the superelevation



Information re Alpine Railways taken from Paper by J.L.V. Harcourt, Proceedings Institute Civil Engrs Vol XCV.

Fig 1.

tion is worked up on the straight, and, consequently, there is no sudden lurch. The practical application is very simple, and the following example may be sufficient to explain the matter.

For instance, take two reverse curves of 8-chain radius with two chains of straight between them; to construct the transition curve, all that is necessary is to lay off parallel tangents at a distance of one-third the offset at one chain, that is, 16½ ins., and from the parallel tangent set out the 8-chain curves in the ordinary way, then the transition curve will meet the circle at a point one chain from the tangent points and will pass midway between the original and the new tangent points, and the origin of the curve will be one chain back from the tangent point.

It will be seen in the above example that the only extra work involved is to set out the curve 16½ ins. inside the ordinary curve where no transition curve is introduced.

One question that deserves attention is the easing changes of grade by vertical curves; where the changes of grades are not properly eased off, the risk of breaking couplings is very great, especially the case where there is an abrupt change from a falling to a rising grade.

Permanent Way.—The standard rail for the New South Wales railways is an 80 lbs. to the yard steel rail, and at present no less than 200 miles exist. The sleepers are laid 2 ft. 7 ins. center to center, each sleeper averaging in weight over 2 cwt. 1 qr. The lightest rails are 71-lb. steel rails, but much of the road is 75-lb. iron and steel, and 80-lb. steel rails. The question of the weight of a rail, however, is rather one of economy than security, as the 71-lb. steel rail is sufficiently strong to carry an engine weighing considerably over 58 tons.

A table is given on the following page showing the weight of engines run upon those rails and the weight of rails in use in other parts of the world, together with some particulars of the weight borne by some of the driving wheels.

At the Annual Convention of Master Mechanics and Locomotive Superintendents, held in 1891, a committee of the Society reported that the limit of weight per driving axle should be 14½ tons for rails under 60 lbs., and 16 tons 1 cwt. for rails over that weight.

The Lancashire and Yorkshire Company have running upon their lines about 300 engines, with a weight upon a pair of driving wheels of from 15 tons 10 cwt. 1 qr. to 17½ tons; the Great Western of England

Railway.	Total weight in working order.				Maximum weight on one axle.		Weight of rails per yard.		Weight of steel rails per yard per ton on each wheel.		Authority for weights of engines.
	Engine.		Engine and Tender.				Iron.	Steel.	Lightest rail.	Heaviest rail.	
	Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.	Lbs.	Lbs.	Lbs.	Lbs.	
Central New Jersey	55	6	.....		19	14	56 and 65	62 and 70	6	7	"R. R. Gazette," 12-2-92.
Baltimore and Ohio	59	8	93	6	15	14	60 and 80	67	8½	8½	" " Nov. 27th, 1891.
New York Central	57	1	89	6	17	16	none	66 to 80	7½	9½	" " 13-9-91.
Philadelphia and Reading	50	0	.....		17		none	56 to 90	6	10	" " Nov. 13th, 1891.
St. Louis	58	13	92	19	15	6	.....	67	8	8	" " 1-1-92.
Erie	58	0	92		15		.....	56 to 65	7.4	8.7	" " 13-6-90.
Atchison and Topeka	58	0	.....		15	9	.....	56 to 65	7	8	" " 15-8-90.
Chesapeake and Ohio	59	5	.....		15	6	.....	56 to 75	7.3	9.8	"R. R. Journal," July, 1890.
Master Mechanics	59	8	.....		14	18	.....	.....	.....	.....	" " 8-1 92.
L. & N. W. Railway	52	0	77	2	15	10	.....	84 to 90	10½	11½	"Engineering," Nov. 13th, 1891.
North Eastern	46	13	86	13	17	15	.....	90	.....	10	"R. R. Journal," May, 1890.
Great Northern	45	3	78	11	17		.....	82	.....	9½	"Engineering," May 20th, 1890.
N. S. W., 10-wheel Baldwins	58	7	90	6	15	5	75	71 to 80	9½	10.4	
Eastern, of France	54	18	97	1	16	2	.....	69 to 89	8½	11	"Engineer," March 4th, 1892.

carry 15½ tons to 16½ tons on a pair of wheels; the Midland Railway Company carry 17½ tons on the driving axle of an express engine. It is a practice in America to run engines with as great a weight as 17 tons to 19 tons on one axle, at high speeds, on rails varying in weight from 56 lbs. to 70 lbs.

The Spacing of Sleepers.—In dealing with this question it must be borne in mind that it is not determined solely by questions of strength, but by the fact that a sufficient bearing area must be obtained for the rail on the sleeper for the class of wood used, and for the sleeper on the ballast. With the soft woods in use in Europe and America, it is absolutely necessary that the bearing surface of the rail and sleeper should be large enough to prevent the rail cutting into the sleepers. In England this is guarded against by using cast-iron chairs, and in America by placing the sleepers closer together. Even with this precaution, continual trouble is experienced in consequence of the rails and chairs cutting into the soft woods, which involves constant attention to prevent the rails from becoming loose.

The iron bark sleepers we possess in this colony are so hard and durable that the fastenings retain their hold exceedingly well for years, and the rail cuts but slightly into the timber.

A very important matter to be considered in connection with the permanent way is the weight of the road, as compared with that of the rolling stock passing over it, as the weight of the road as a whole measures its resistance to the blows of traffic. The following statement shows the weight of 1 mile of permanent way of the three types of road in this colony, compared with the standard main line of a leading railway company in England.

Weight of 1 mile of permanent way.		Tons.	Hundred-weights.	Quarters.
New South Wales Railways.....	75-lb. D. H. iron rails laid in 27-lb. cast-iron chairs upon iron bark sleepers 9 ft. long by 10 ins. wide, by 5 ins. thick, 3 ft. apart centers.	384	7	3
	71½-lb. T steel rails laid upon iron bark sleepers 8 ft. long by 9 ins. by 4½ ins., 2 ft. 7½ ins. centers.....	282	2	2
	71½-lb. T steel rails laid upon iron bark sleepers 9 ft. long by 10 ins. by 5 ins., 2 ft. 7½ ins. centers.....	346	8	1
	80-lb. T steel rails laid on iron bark sleepers 9 ft. by 10 ins. by 5 ins., 2 ft. 7 ins. centers..	371	1	3
English, London and North Western	84-lb. bull-headed rails laid in 45-lb. cast-iron chairs upon creosoted Baltic sleepers 9 ft. by 10 ins. by 5 ins., 3 ft. apart centers.....	341	1	1

The weight of the standard Baltic timber in use on the leading lines in England, 9 ft. long by 10 ins. by 5 ins., creosoted, is 160 lbs., and in this colony that of the iron bark sleepers of similar dimensions is 252 lbs. As regards the durability, the life of the iron bark sleeper is fully double that of the Baltic sleeper.

In this colony's railways the rails are generally laid on sleepers placed 2 ft. 7 ins. to 2 ft. 8 ins., center to center, on the straight; and in sharp curves of less than 15 chains radius, sleepers are placed as close as 2 ft. 4 ins., center to center, and in curves from 15 to 30 chains radius, 2 ft. 9 ins., center to center. It is well known to engineers that the spacing of sleepers plays the most important part in the stability of a railway.

From the "Encyclopædia Britannica" of 1886 the following facts from articles written by D. K. Clark, C. E.; Professor A. T. Hardy and A. M. Wellington, C. E., are extracted:

In the United States the Vignoles rails are universally used for railways. No railways with any considerable traffic are now laid down with less than 60 lbs. per yard. The Pennsylvania railway, laid to a gauge of 4 ft. 9 ins., is constructed of flange rails, in lengths of 30 ft. Allowance for expansion, when rails are laid in winter, is provided by laying the rails $\frac{5}{16}$ in. apart, endwise; in summer a space of only $\frac{1}{16}$ in. in width is allowed. The cross-sleepers are 8 ins. wide by 7 ins. deep by 8½ ft. in length; they are laid so closely that the maximum distance apart between the centers does not exceed 2 ft. There are 16 sleepers for each length of 30 ft., and the sleepers at the joints are laid with a clearance of over 10 ins. between them. The rails are fastened with spikes to the sleepers at the inside and outside. The width of the double line of way at the formation level is 31 ft. 4 ins. in cuttings, and on embankments the width of formation is 24 ft. 2 ins., sloping from the center at the rate of 1 in 20. The ballast is laid to a depth of not less than 12 ins. under the sleepers, and is filled into the level of the upper surface of the sleepers. Where stone ballast is used it is often broken to a uniform gauge of 2½ ins. For double lines, large stones are placed in the bottom at the center between the lines, to allow for drainage.

The sleepers (in America called ties or cross-ties) are usually of white oak, hewn on top and bottom with the natural surface of the tree on the sides. The usual dimensions are 6 to 7 ins. thick; 8, 8½ to 9 ft. long; and 8 to 10 ins., or even 12 ins., face. The usual rule is to place them 2 ft. or less apart, and 2 640 to 2 700 to the mile. The large bearing surface thus afforded has especially favored the use of the flat-based or Vignoles rail, and it is in exclusive use throughout

North, and for the most part of South, America. The rails now most largely rolled weigh from 56 to 65 lbs. per yard. In the north and east rails of 70, 72, 75 and 80 lbs. sections are in limited but increasing use. The close propinquity of sleepers gives much greater stiffness to the rail than comparative weight alone would indicate, a 60-lb. rail being fully equivalent in stiffness and strength to an 80-lb. rail, supported on chairs 3 ft. between centers.

From the above it will be seen, though the rail is lighter, the spacing of the sleepers makes the road equal to the New South Wales standard 80-lb. rail with sleepers spaced 3 ft. apart.

For comparison, it may be stated that Belgium has about 3 250 miles of railway, of which about 2 000 miles are owned and operated by the State. The standard rails of flange section, 29 ft. 6 ins. long, weigh about 104 lbs. per yard. They are fastened to the ties by screw spikes, while ordinary spikes are used for the lighter rails. The rails are laid with square, suspended joints, spliced by heavy angle bars, 2 ft. 3 ins. long, with four bolts, the angles being fastened to the ties by screw spikes, and on all ties and tie plates. There are 12 ties to a rail length, spaced 2 ft. at the joints, and 2 ft. 4 ins. to 2 ft. 8 ins. intermediate.

In New South Wales railways the ballast is laid to a depth of 12 to 15 ins., and no less than 700 000 tons of ballast have been used; out of that quantity 600 000 tons have been blue metal, hard quartz or slag. In regard to the ordinary repairs to the permanent way, it may be mentioned that for relaying alone there has been paid during the last three and a half years the sum of £230 000.

Owing to the introduction of heavier rolling stock to meet modern requirements, it has been found necessary by all the large railway companies throughout the world to strengthen the permanent way on their busier lines. Heavier rails are being introduced, and sleepers are closer spaced; and this is not done in the interests of safety alone, but also on economical grounds, as on many lines the existing permanent way was sufficiently strong to carry the increased weights at the greater speed now aimed at.

From the New South Wales *Railway Budget* the table on the following page giving some particulars of the heavier rails recently adopted on the several lines is extracted:

Railways.	Dimensions and Weight of Rails.							Sleepers.	
	A, Height of rail.	B, Width of bottom (flat).	Width of webb.	Proportion B. ÷ A.	Weight per yard	Length of rail.	Thickness of webb.	Number per pair of rails.	Average distance between sleepers.
	Inches.	Inches.	Inches.	Percentage.	Pounds.	Feet.	Inches.		Inches.
Austrian State Railways, 1891	5.344	4.716	2.358	88.3	86⅛	32⅝	0.707	13	30.261
						45¼	.....	19	31.047
Prussian State Railways, 1885	5.266	4.126	2.279	78.4	67	29½	0.432	10	35.37
" " " 1891	5.423	4.323	2.829	79.7	90	29½	0.55	11	32.147
Gothard Railway	5.698	5.109	2.751	89.7	93¼	39½	0.571	15	31.44
								16	29.475
Paris-Lyon-Mediterranean	5.580	5.109	2.593	91.6	94⅛	39½	0.55	15	31.44
								16	29.475
Philadelphia and Reading	4.991	4.991	2.868	100	90	39½	0.668	15	31.44
								16	29.475
New South Wales	4.907	5	2.5	1.019	80	30	0.812	11	

From the latest statistical information available it appears that there are about 383 600 miles of railways in operation throughout the world. Of these 207 144, or 54.1%, are in America; 138 000, or 35.9%, in Europe; 21 100, or 5.5%, in Asia; 11 984, or 3.1%, in Australia; and 5 372, or 1.4%, in Africa. The mileage of the United States, viz., 166 410 miles, is greater than that of the whole of Europe.

If the five leading European countries are taken, they stand thus in regards to mileage : Germany, 26 623 miles; France, 24 157 miles; the United Kingdom, 20 090 miles; Russia, 19 251 miles; and Austro-Hungary, 16 837 miles.

If the ratio of mileage to the number of inhabitants is taken, the countries rank differently. France comes first, with 6.2 miles for each 10 000 inhabitants; Germany second, with 5.6; the United Kingdom third, with 5.2; Austro-Hungary and Russia, fourth and fifth, with 4.1 and 2.0 respectively.

The Australian Colonies show far higher mileages; for instance, in Queensland we have 56.6 miles for every 10 000 inhabitants; South Australia follows with 52 miles; then New Zealand with 28.3; Victoria with 25.2; and New South Wales, 20 miles.

Considering the number of persons per mile of line, the figures are: France, 1 582; Germany, 1 706; the United Kingdom, 1 913; Austro-Hungary, 2 434; Russia, 4 987; Queensland, 176; South Australia, 196; New Zealand, 358; Victoria, 399; and New South Wales, 501.

In the above comparisons the United Kingdom ranks third among the European States; but it must not be overlooked that the size of the country and the density of population are important factors in railway matters. If these be taken into consideration the United Kingdom ranks first with 318 persons and 0.17 mile of line per square mile; Germany takes second place with 225 persons and 0.13 mile; then follows France with 187 persons and 0.12 mile; Austro-Hungary with 155 persons and 0.07 mile; and, lastly, Russia with 46 persons and 0.01 mile of line per square mile.

The table on the following page gives detailed information respecting railway mileage, population, miles of line per 10 000 inhabitants, and the number of persons to each mile of railway.

Rolling Stock.—In the development of railways the design of rolling stock has gone through various stages, and in early days a very wide latitude was given for experiments, more especially in America,

Countries.	Miles of Railway.	Population.	Miles of railway per 10 000 inhabitants.	Persons per line of mile.
Europe.				
Germany	26 623	46 875 705	5.6	1 706
France	24 157	38 218 903	6.3	1 582
The United Kingdom	20 090	38 443 295	5.2	1 913
Russia	19 251	96 009 247	2.0	4 987
Austro-Hungary	16 837	40 986 000	4.1	2 434
Italy	8 112	30 947 306	2.6	3 813
Spain	7 452	17 550 246	4.2	2 355
Norway and Sweden	2 503	6 752 800	3.7	2 698
Belgium	2 263	6 093 798	3.7	2 693
Switzerland	1 875	2 934 057	6.4	1 565
Denmark	1 203	2 172 705	5.5	1 805
Other European States	7 634	22 907 438	3.3	3 001
Total	138 000	349 873 000	3.9	2 536
America.				
United States	166 410	62 875 956	26.4	378
Canada	15 000	5 075 855	29.6	338
Argentine Republic	5 427	4 086 492	13.3	750
Remaining States	20 307	49 296 697	4.2	2 427
Total	207 144	121 335 000	17.1	585
Australia.				
New South Wales	2 359	1 182 500	20	501
Victoria	2 903	1 159 729	25.2	399
Queensland	2 320	410 330	56.6	176
New Zealand	1 869	668 651	28.3	358
South Australia	1 660	325 723	52	196
Western Australia	499	49 835	124.7	100
Tasmania	370	146 667	26.7	393
Total	11 984	3 943 435	30.5	329
Asia.				
India	17 564	210 754 000	0.83	12 000
Japan	1 428	39 607 000	0.36	27 736
Russian Transcaspian	901	7 284 000	1.12	8 085
Dutch Colonies	814	22 820 000	0.36	28 034
Ceylon	192	3 000 000	0.64	15 625
China	124	404 180 000	0.003	3 259 506
All other countries	77	142 954 000	0.005	1 856 546
Total	21 100	830 599 000	0.254	39 364
Africa.				
Algeria and Tunis	1 925	5 317 000	3.7	2 762
Cape Colony	1 863	1 524 000	12.3	818
Egypt	960	6 806 000	1.5	7 090
Natal	376	530 000	7.1	1 409
Mauritius	92	372 000	2.4	4 044
All other countries	156	188 772 000	0.09	1 210 076
Total	5 372	203 321 000	0.27	37 849
Grand total	383 600	1 509 071 435	2.5	3 943

where patents for every possible contrivance were taken out; but at the present time a very strong tendency has set in to reduce every thing to a standard, and although the Americans are keenly alive to all improvements, yet, as far as possible, it is attempted to reduce every detail down to a standard form. Nor is this tendency confined to America, as for many years past the large railway companies of England have been concentrating their attention in the same direction.

A very interesting series of standard types of locomotives and carriages has been developed on the London, Brighton and South Coast Railway. The whole of the rolling stock on these lines has been constructed in the company's workshops to their own templates, thus enabling all repairs and renewals to be rapidly and economically carried out. The carriages of this line are of a very neat pattern, being built to a uniform design, and have a very good appearance. The central buffer and draw gear of the carriages on the London and Metropolitan Railway are very ingenious and enable the train to pass round sharp curves with great ease. The London and North Western Railway has also carried out the system of building their rolling-stock to a uniform pattern. This company, too, manufactures the whole of their stock in their own workshops.

In England the individual railway companies have adopted standards of their own, yet the standards of no two companies agree; for instance, each of three of the leading companies running from London has its own type of engines and carriages, and although each has the same class of traffic to deal with, it has engines of entirely different types in use.

On the Midland Railway the express traffic has been worked with four coupled engines with wheels 7ft. in diameter, cylinders 18 ins. diameter and 26-in. stroke, with a four-wheeled bogie in front. On the Great Northern Railway, the engines used for fast traffic have driving wheels 8 ft. in diameter, outside cylinders 18 ins. and 28 ins. stroke. On the London and North Western Railway, the express traffic was worked with four coupled engines, with inside cylinders 17 ins. diameter, with 24-in. stroke and 5 ft. 6-in. wheels.

In regard to locomotives, a long article might be devoted to the comparison of the practice of the various countries. In America there are a number of distinct types, classed according to the number and arrangement of the wheels, but with special features of design

and detail introduced by the builders. There is a great diversity of types of engines in England. Tank engines, usually with side tanks, are generally used for the suburban traffic in England and New South Wales; while for the same class in America, engines have generally a tank at the frame. In England the various companies have in a more or less perfect way adopted standards of their own, but the tendency of American practice is to adopt a far more general system of standards; for the vast extent of railways in America, owned by a large number of different companies, having an enormous traffic necessitating the stock of one company traveling over the lines of other companies, it is evident that if the various details of car or wagon stock could all be made to the one system of standards, any repairs that might be necessary to the stock of one company could be quickly executed.

In New South Wales there are 28 recognized types of engines, including all the new American and English engines, and a total stock existing at present of 481 engines; 331 of these belong to four types. Some of the engines have been manufactured in the Colony, and the others have been imported from the following firms, viz.: Dubbs & Co., Glasgow; Manning, Wardle & Co., Newcastle-on-Tyne; Beyer, Peacock & Co., Manchester, and Burnham, Parry, Williams & Co., Baldwin Locomotive Works, Philadelphia, U. S. A.

With regard to the height of the center of the boiler the express engines of this colony are lower than a good many express engines. For example, on the Central of New Jersey, an express engine running at extremely high speed, is 9 ins. higher than the Baldwin engines of New South Wales; the Baltimore and Ohio engine is 1½ ins. higher; the New York Central engine, which runs the Empire State Express, one of the fastest trains in the world, and going around numerous curves, is 10½ ins. higher. Cleveland, Cincinnati, Chicago and St. Louis express trains are the same as in this colony.

The North Eastern Railway in England express engine is 2 ins. higher, and one of the engines is 1 in. lower. The Great Northern standard express engines, which have for many years run about the fastest trains in England, are 5¾ ins. lower, but the wheel is 3 ft. greater in diameter.

Of course, the vital thing in these matters is the height of the center of gravity above the rails, and it is found, by approximate calculations, that the Great Northern express engine is about 3 ins. higher

in the center of gravity than the Baldwin engines running in this colony; therefore, the writer thinks that the center of gravity of engines in use in this country is perfectly safe, that is to say, the 10-wheeled locomotives have a lower center of gravity than any of the English or American engines just quoted.

The table of figures on the following page is submitted.

The general dimensions of the 10-wheeled Baldwin engine in use in this colony are as follows:

Diameter of cylinder	21 ins.
Stroke of piston	24 "
Diameter of drivers	61 "
Area of fire grate	27.7 sq. ft.
Area of heating surface in firebox (copper)	105.6 "
Area of heating surface in fire tubes (brass)	1 822.5 "
Total	1 928.1
Tractive force per pound of M. E. P. per square inch	171 lbs.
Maximum boiler pressure	160 "

Total weight of engine in running order, with two-third glass of cold water and sandboxes full:

	Tons.	Cwts.	Qrs.
Weight on driving wheels	43	11	0
Weight on bogie wheels	14	16	0
Total weight of engine	58	7	0

	Tons.	Cwts.	Qrs.			
Weight of tender, empty	13	12	0			
Weight of 3 000 galls. water.	13	8	0			
Weight of 5 tons coal	5	0	0			
				32	0	0
Maximum weight in running order of engine and tender				90	7	0

The general dimensions of the 30 new 10-wheeled express locomotives built by Messrs. Beyer, Peacock & Co., of Manchester, England, and now running on the New South Wales Railways, are as follows:

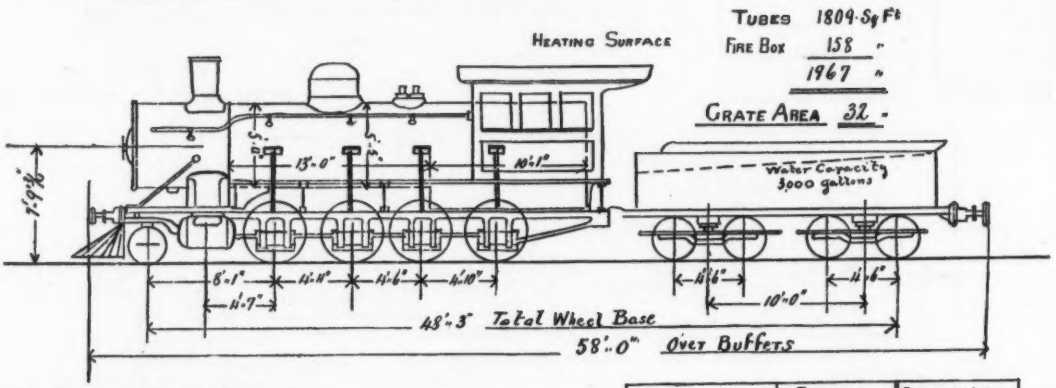
Cylinders, diameter	20 ins.
Stroke of piston	26 "
Number of coupled wheels	6
Diameter of coupled wheels	5 ft.
Diameter of bogie wheels	3 " 3 ins.
Heating surface—Firebox	130 sq. ft.
Tubes	1 786 "
Total	1 916 "
Grate area	27 "
Boiler pressure	160 lbs.

Heights of Center of Boiler, Gravity, Etc., Various Express Locomotives.

Railways.	Number of wheels coupled.	Center of boiler above rail.		Diameter of wheels.				Diameter of boiler.	Weight of engine in working order.		Center of gravity above rail.	Firebox above or between frames.	Remarks.
				Driving.		Bogie.							
		Feet.	Inches.	Feet.	Inches.	Feet.	Inches.	Inches.	Tons.	Cwts.	Feet.		
Central of New Jersey	4	8	6	5	8	3	0	58	55	6	5.13	above	Runs regularly of 70 miles an hour.
Baltimore and Ohio	6	7	10½	5	2	2	6¼	64	59	8	4.60	between.	
New York Central	4	8	7½	6	6	3	0	58	57	1	5.24	above	Runs fastest train in world.
Philadelphia and Reading	4	8	9	6	6	4	0	57½	50	0	5.22	above	Runs regularly over 70 miles an hour.
Cleveland, Cincinnati, Chicago and St. Louis	6	7	9	5	6	2	6	60	58	13	.....	between.	
Erie	6	8	5½	5	8	2	9	60	58		.....	above.	
North Eastern	2	7	11	7	7¼	3 / 4 trailing.	7¼ / 7¼	51	46 about	13	5.03	between.	Attained highest speed, 86 miles an hour, ever made in England.
North Eastern	4	7	8	6	8½	3	7¼	57½	47	10	4.79	between.	Runs fast trains on lines over sharp curves.
Great Northern	2	7	3¼	8	1½	3	11	50	45	3	4.79	between.	Has run very fast trains in England for years.
New South Wales	6	7	9	5	1	2	6	62	58	0	4.52	between.	
New South Wales	6	7	8	5	0½	.....		53	56	15	.....	between.	

Note.—The New South Wales 10-wheelers have, therefore, a lower center of gravity than any of the above English and American engines, though the latter engines run the fastest trains in the world.

—CONSOLIDATION GOODS BUILT BY THE BALDWIN C^{o}Y —



NOTE: The Two middle pairs of Coupled Wheels are Flangeless

— Cylinders 21" x 26" Stroke —

Total weight on 4 sets of driving wheels when loaded 56. 15. 3

		Empty	Running Order
		T. C. Q.	T. C. Q.
Weight	Engine	55 . 15 . 3	61 . 12 . 2
"	Tender	13 . 12 . 0	32 . 0 . 0
"	Total	69 . 7 . 3	94 . 12 . 2

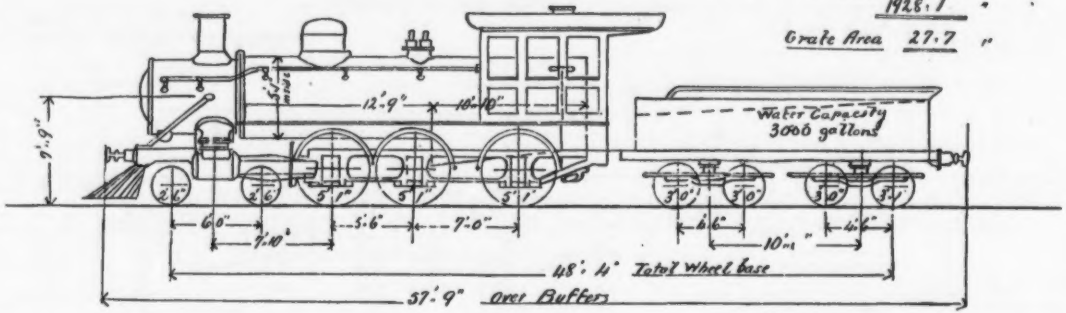
FIG 2.

— 10 WHEELED EXPRESS:— BUILT BY THE BALDWIN COY —

Heating Surface

Tubes 1822.5 sq ft
Fire Box 105.6 "
1928.1 "

Grate Area 27.7 "



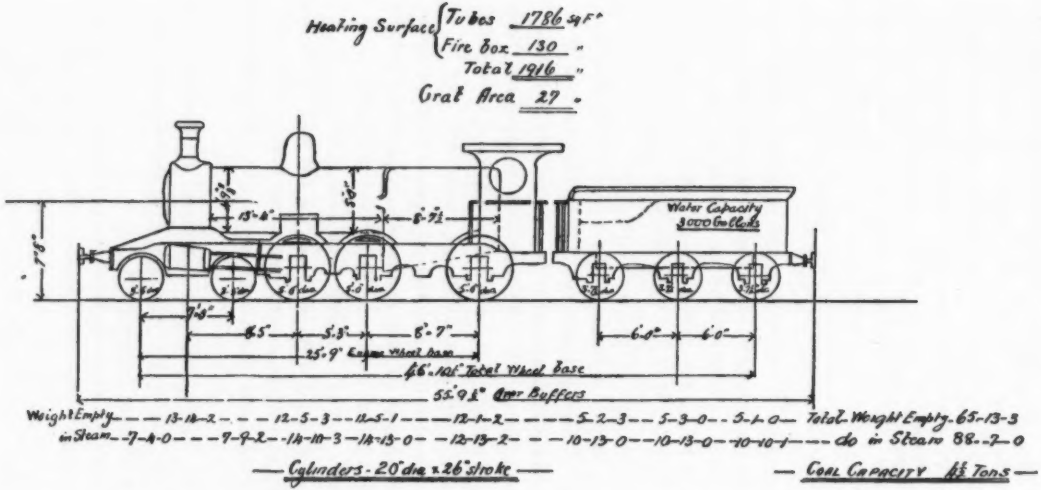
Note: The Centre Pair of Coupled Wheels Are Flangeless

Cylinders 21" x 24" Stroke

Total Weight on 3 sets of driving wheels when loaded 43.11.0 (T. C. Q.)

	EMPTY	Running Order
	T. C. Q.	T. C. Q.
Weight Engine	51.5.0	58.7.2
" Tender	13.12.0	32.0.0
" Total	64.17.0	90.7.2

FIG. 3.


Heating Surface { Tubes 1786 sq ft
Fire box 130 "
Total 1916 "
Grat Area 27 "
Water Capacity 3000 Gallons
13'-6"
8'-7½"
7'-6"
7'-0"
8'-5"
5'-3"
8'-7"
25'-9" Engine Wheel Base
46'-10" Total Wheel Base
55'-9½" over Buffers
6'-0"
6'-0"
Weight Empty — 13-18-2 — 12-5-3 — 12-5-1 — 12-1-2 — 5-2-3 — 5-3-0 — 5-1-0 — Total Weight Empty 65-13-3
in Steam — 7-4-0 — 7-9-2 — 14-10-3 — 14-13-0 — 12-13-2 — 10-13-0 — 10-13-0 — 10-10-1 — do in Steam 88-7-0
— Cylinders - 20" dia x 26" Stroke —
— Coal Capacity 4½ Tons —

— 10 WHEELED (ENGLISH) EXPRESS BUILT BY BEYER PEACOCK & Co —

FIG. 4.

	Tons.	Cwts.	Qrs.	
Engine—Weight empty.....	50	7	0	
In steam.....	56	10	3	
Tender—Coal capacity.....	4	10	0	
Water capacity.....				3 000 galls.
Weight, loaded....	31	16	1	
Weight, empty....	15	6	3	

Total weight of engine and tender in working order.....	Tons.	Cwts.	Qrs.
	88	7	0

Consumption of fuel, 42 to 44 lbs. per mile.

All the engines are fitted with the most modern improvements, such as the Westinghouse automatic brake applied to engine, tender and carriage wheels; sight-feed lubricators for lubricating the cylinders and side valves, and two of Gresham & Craven's improved injectors, Nos. 8 and 9, for feeding the boilers. The boilers are made of steel, having fireboxes of the Belpaire pattern and brass tubes.

Mr. Lentz, Locomotive Engineer of the Government Railways, Germany, read an interesting paper on "The World's Locomotives," at a meeting of the German Engineering Association held last year.

He gave the total number of locomotives running on the earth's surface as about 109 000, divided as follows: Europe, 63 000; America, 40 000; Australia, 2 000; Asia, 3 000, and Africa, 700.

In Europe, Great Britain and Ireland possess 17 000 engines; Germany, 15 000; France, 11 000; Austro-Hungary, 5 000; Italy, 4 000; Russia, 3 500; Belgium, 2 000; the Netherlands and Spain, 1 000 each; Switzerland, 900; and the remaining countries, 2 600.

In America the United States heads the list with 35 000 engines; Canada follows with 2 000; and the remaining States claim 3 000.

In Asia, British India claims 2 500 engines, and the other countries 800.

In Australia, New South Wales possesses 481 engines; Victoria, 462; Queensland, 255; South Australia, 241; Tasmania, 52; New Zealand, 266; and Western Australia, 24.

Railway Carriages.—In America there is a large amount of money and skill employed in the construction, equipment and decoration of cars. One feature about them is the comfort, convenience, luxury and artistic finish. In England, dining cars have been introduced, but the lack of communication with the rest of the train is a drawback to their use. Drawing-room, saloon, sleeping and other such cars are also

used in England. Many of the modern carriages are carried on four or six wheel trucks instead of upon the older system of rigid axles. Some of them are fitted with lavatory accommodation, but the arrangements are crude, and they are not properly looked after. In New South Wales, there are various types of railway carriages used, viz., the sleeping cars, Pullman cars, American, Ashbury, lavatory, express and other cars. All these are principally manufactured by firms of New South Wales, and any repairs or alterations, etc., are carried out in the Government workshops. One feature about them is the comfort, convenience, luxury and artistic finish.

A brief description of some of the various types of cars in use is added:

Type.	Description.
Redfern	A double bogie carriage on eight wheels, the body made in six compartments.
Cleminson	Same as the Redfern in every respect, excepting the bogie, in which a slight difference is made in construction.
American	Long car, American platform, promenade through the center; bogie same as the Cleminson.
Ashbury	Carriage with two Ashbury bogies (six wheels), and divided into first and second class compartments.
Eight-wheel Radial	Built after the Redfern type in body. Bogies substituted by four pair of wheels at equal distances apart.
Six-wheel Radial	A carriage with six compartments and three pair of wheels, one pair under each end and one pair under center of carriage.
Four-wheel	Small carriage with three and four compartments and two pair of wheels.
Lavatory	Double bogie carriage, six compartments, on eight wheels, with lavatory inside.
Express	Same build as lavatory carriages, but contains no lavatory compartments.
Ordinary	A carriage resembling the Redfern type in construction, but have two ordinary or common bogies of eight wheels.

Each of the above types can either be a first-class, second-class or composite carriage.

In New South Wales the Westinghouse automatic brake is universally used on passenger trains.

Speed.—In the matter of average speed, it must be admitted that the ordinary express trains on English railways make better time than the same kind of trains on Australian and American railways. The *Central European Railway Gazette* publishes a tabulated statement showing the total daily mileage and average speed per hour of express trains running over the railways of several continental countries. The express trains of the Prussian Government Railway head the list of average speed with 30.944 miles per hour, which, however, is .076 mile less than obtains in New South Wales. Belgium, with its almost level lines, shows the lowest average with 29.565 miles. This is, however, only 3.685 miles in advance of the average speed of our mail trains, which have to climb steep grades and are also delayed by frequent stoppages.

Country.	Total daily mileage.	Time occupied.		Average speed per hour, inclusive of stoppage.
		Hours.	Mins.	Miles.
France	52 783.3	1 758	15	30.013
North Germany	28 703.8	931	7	30.821
Prussian Government Lines	27 588.1	890	53	30.944
The Netherlands	9 107.8	296	7	30.758
Belgium	6 781.3	228	25	29.565
New South Wales	976	31	28	31.02
N. S. W. Mail Trains	2 506	96	49	25.88

The new 10-wheeled express locomotives built by Messrs. Beyer, Peacock & Co., of Manchester, for the New South Wales railways are employed in working the express and mail trains over the southern, western and northern lines, their running being confined to the difficult portions of the road, such as from Sydney to Junee, on the south (286 miles); Sydney to Dubbo, on the west (278 miles), and Sydney to Newcastle, and Singleton to Jennings, on the north (446 miles). Their load over the 1 in 30 grades is 165 tons, and in the 1 in 40 grades 205 tons; and in a recent trial one of these engines hauled a train weighing 225½ tons behind the tender up a grade of 1 in 42 at a settled speed of 20.45 miles per hour, developing 1 080 H. P.

To give some idea of the speed at which these trains are regularly running, the Melbourne express train, which weighs 115 to 205 tons, is scheduled to travel over the section Sydney to Junee and return at an average speed of 34.6 miles per hour, exclusive of stoppages, and the train has to be lifted through an accumulated vertical distance of more than 8 000 ft. over rising grades on the down journey alone.

In the following table will be found the speeds of the Baldwin engines, obtained from five trips made, the train being made up of Pullman sleeping cars and first-class lavatory carriages:

No. of Trip.	Gradient.	Mean speed on the whole length of gradient.	Weight of train, exclusive of engine and tender.		Remarks.
		Miles per hour.	Tons.	Cwts.	
1..	1-40	18.50	179	5	Length of gradient, 2½ miles.
2..	1-40	20.15	157	12	Several curves 16 chains radius on first mile.
5..	1-40	21.09	157	12	About 2 miles 1-30 and ¾ mile.
3..	1-30	18.87	121	14	Of 1-33, curvature moderate.
4..	1-30	15.17	144	2	

An interesting return has been published by the Board of Trade of the fast trains running on week days between London and Birmingham, Bradford, Hull, Brighton, Bristol, Derby, Leeds, Leicester, Norwich, Liverpool, Manchester, Newcaste-on-Tyne, Nottingham, Portsmouth and Sheffield, giving in each case the alternative lines of railway, with the distance, the average time occupied on the journey, and the average rate of speed per hour on both up and down journeys. From the details there given, the following figures are extracted, showing the average speed per hour by the fastest trains on each route down from London and up to London:

Between London and—	Railway.	Down.	Up.
Birmingham	Great Western	45	44
"	London and North Western	45½	45½
Manchester	Midland, via Leicester	45.2	45.4
"	Midland, via Kettering and Nottingham	47	
"	London and North Western	46¾	47
"	Great Northern	47.764	47.764
Liverpool	London and North Western	43½	45
"	Midland	45.2	46
"	Great Northern	43.468	40.629
Bradford	Great Northern	47.407	46.08
"	Midland, via Leicester	47.3	49.7
"	Midland, via Kettering and Nottingham	48.7	47.6
Leeds	Midland, via Leicester	47.9	48.8
"	Midland, via Kettering and Nottingham	49.3	49
"	Great Northern	47.974	48.391
Sheffield	Midland, via Leicester	44.8	47
"	Midland, via Kettering and Nottingham	49.3	48.8
"	Great Northern	51.157	50 625
Nottingham	Midland, via Kettering	51.6	51.7
"	Midland, via Leicester	49.7	
"	Great Northern	48	46
Bristol	Great Western	44	44
Hull	Great Northern	45.461	44.727
Newcastle-on-Tyne	Great Northern	48.683	47.130
Norwich	Great Eastern	38.3	37.3
Brighton	L. B. and S. C.	40.39	43.30
Portsmouth	London and South Western	36	37
"	L. B. and S. C.	43.29	43.29

Lighting of Railway Carriages.—At the present time the railway carriages belonging to the Government of New South Wales are lighted with gas. An iron vessel, cylindrical in shape, is placed under the floor of each car, and the pipes are laid from this to each compartment.

The question of the electric lighting of trains has received a good deal of attention on a number of railways, but, so far, the constant disadvantages of the system have been so heavy as to prevent the general adoption of electric lighting. No doubt it has great advantages in that the cars are kept much cooler and the light can be more evenly diffused. A trial has, on more than one occasion, been made on the lines of this colony, and about three years ago a sleeping car was fitted up under the direction of the Railway Commissioners by the Superintendent of Telegraphs, and made a number of journeys between Sydney and Albury, the light eliciting much appreciation; but it was found to be so costly, to work in comparison with other lighting systems, and to require such additional dead weight in the shape of accumulators, that the experiment had to be given up. Interest in the question is being revived by the proposal to light the carriages upon the South Australian lines with electricity. This experiment, however, is one that requires to be made with caution, and, judging from a recent extract from the *Railway Age*, it would appear it has been given up on other lines.

English papers announce that lighting carriages by electricity is to be abandoned in favor of compressed oil gas on the Midland Railway, as it has been found too expensive and unreliable. This company has made every endeavor for a number of years to use the electric light in its carriages, and its decision, following so soon on that of the Brighton Company, may be regarded as the *coup de grâce* of the system—at any rate for several years.

In America, in spite of many attempts, electricity is now used for lighting only in a few instances, and that for special train service. While but little definite information regarding the cost of maintenance is available from the numerous railroads that experimented in this line, the data so far received are not reassuring. The writer knows of but two instances in this country where electric train lighting has shown evidence of being a paying investment from the railroad standpoint, that is, the train could, individually, aside from any

outside traffic influence, pay all its running expenses and a fair return on the investment over and above those expenses. The systems used in these two instances are dissimilar.

As to the reliability of electricity, in no cases have the railroads that use it felt that they could dispense with the older and tried systems.

Even where the use of electricity has been fairly successful, it is very often necessary in emergencies to have recourse to oil or gas; and the results obtained on the English railways are not surprising. The use of electricity for train lighting will, however, be retarded considerably by the action of the English railways.

Sir George Findlay, General Manager of the London and North Western Railway, England, takes a different view of the present position of affairs, and instead of maintaining that the electric lighting of trains has received its *coup de grâce* through the action of English companies, he rather leans towards the idea that what has been done clearly indicates the direction in which investigations must proceed, and also that beyond doubt electricity will be the lighting medium in the future. The question is yet only in the transitional or experimental stage, and for that reason most of the companies have not attempted to adopt it on anything like a large scale.

There are at least three methods in which a current of electricity may be obtained for lighting a train. A primary battery may be used, or secondary batteries, or the dynamo may be used direct. The majority of railway engineers lean towards the secondary batteries, or the direct action of the dynamo. Probably the ultimate solution of the problem will be found in a combination of the two, or in other words, a dynamo will supply the current when the train is in motion, and the batteries, during stoppages. How the dynamo is to be driven is a question, the settling of which is not marked with the unanimous opinion of engineers, some holding that it should be carried and driven by the locomotive direct, others, that it should be driven by a separate engine, and others, that it should be driven from the axle of the guards van. But whatever method may be ultimately adopted, the writer cannot agree with the idea that electricity has received its death blow, or has even been retarded to any serious extent by the action previously mentioned, and hopes before long to see it entirely replace the oil and gas lamps at present in use.

Mr. Oswald Haes, in a paper entitled "Lighting of Railway Trains," describes the successful experiments carried out in South Australia. In his paper the author deals with the history of electricity as concerned with the lighting of trains, enumerating briefly the various systems, their faults and merits. He then deals with the system experimentally adopted by the South Australian railways. The principle upon which it was to be executed was the axle-driven dynamo, and in conjunction with accumulators, similar in every way to the one that has proved to be eminently satisfactory on the London and Brighton and several other English railways. The dynamo is of the ordinary Brush pattern, and the problem of driving from bogie axles seems satisfactorily solved when the statement is made that it has run well for upwards of four months. It is undoubtedly a very different and difficult matter to drive from bogie stock instead of fixed wheel stock, and the writer believes that the greatest difficulties have been overcome. What little trouble exists now is caused more by errors in detail than in principle, and will consequently be overcome with a little more experience. The couplings are simple, effective and economical, and are protected from interference by unauthorized persons. The system is, of course, specially adapted for trains not liable to be split up, from start to finish of a journey.

After a series of trials which have occupied the engineers for about two years, the Northern Railway of France will take the lead in that country by the installation of apparatus in their trains for illumination by electricity. It is probably known, that the lighting of their third class carriages by oil is as poor as the accommodation; in the second class it is better, but sufficient to discourage reading; while in the first class it has been—since the last few years—very good, due to the employment of round burners. The luminous intensity is now raised by the incandescent lights to 6, 8 and 10 C. P. lamps of 30 volts, according to the class of compartment for which they are destined, the current being 2.9 to 3 watts per candle. The lamps are good for 300 hours. Each carriage carries its own apparatus of 16 accumulators of the type introduced by the "Société du Travail Électrique des Métaux," enclosed in groups of two in small boxes, which themselves are placed in groups of four, in two cases fixed one to each side of the longitudinal frames of the car, and readily accessible from the footboards for renewals. Commutators are placed

STATEMENT.

Countries.	Miles open.	Number of passengers.	Goods. Tonnage.	Train-Miles.			Gross I	
				Passenger.	Goods.	Total.	Coaching.	Goods live st
United Kingdom....	20 191	845 463 668*	310 308 676	171 758 552	148 500 101	323 598 125‡	£35 130 906	£43 23
United States.....	166 410	492 000 000	577 000 000	283 797 000	434 700 000	718 497 000	64 549 893	149 73
Germany.....	26 623	377 000 000	212 000 000	94 392 000	85 077 000	179 469 000	17 320 822	44 63
New South Wales...	2 359	19 918 916	4 296 713	3 683 813	4 672 283	8 356 096	1 189 231	1 91
Victoria.....	2 903	69 546 921	3 654 967	.....	.....	11 807 677	1 644 315	1 45
Queensland.....	2 320	2 370 200*	768 527	.....	.....	3 966 120	348 199	70
South Australia....	1 660	5 744 487	1 104 122	1 595 957	2 582 329	4 178 286	349 421	86
Tasmania.....	377	725 724	161 141	.....	.....	908 694	109 888	5
New Zealand.....	1 869	3 555 764	2 122 987	2 696 314 (3)	314 175	3 010 489	406 412	70
India.....	17 564	122 855 337	26 158 953	.....	.....	60 800 165	4 846 101	9 75
Ceylon.....	192	3 076 828*	281 499	.....	.....	690 070	86 528	187
Belgium.....	2 012	67 432 178	2 631 502	14 239 246	10 507 319	24 746 565	2 060 264	3 64

Remarks.—* Exclusive of season ticket journeys. ‡ Includes 3 339 428 miles run by mixed trains. (1) Includes £3 498 9 earnings. (3) Passenger and mixed. (4) Includes £424 000 miscellaneous. (5) Includes £3 123 miscellaneous. for miscellaneous service.

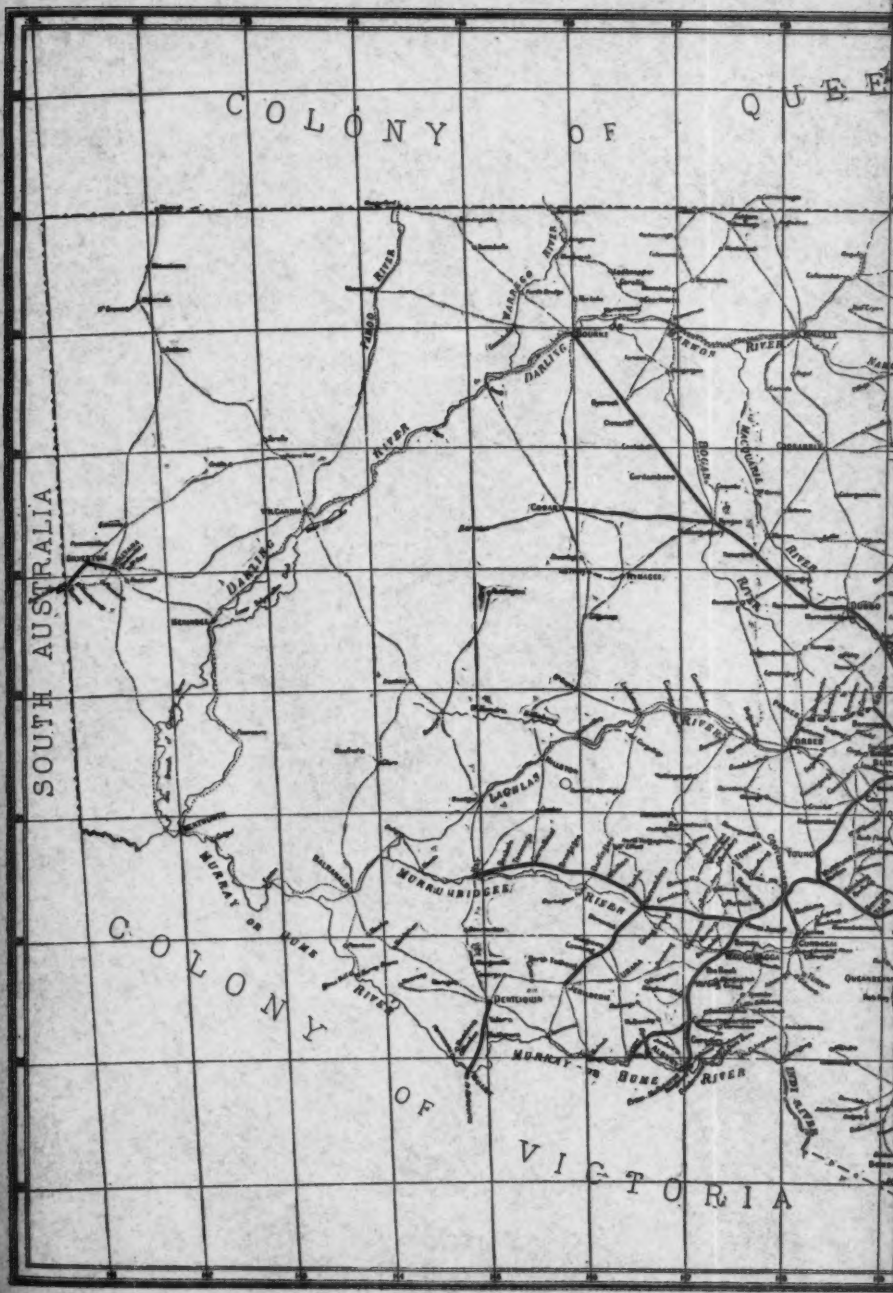
Note.—The information for the United Kingdom, India, Ceylon, United States, Germany, Belgium, is for the year ending South Australia for the year ending June 30th, 1892, and for New Zealand to March 31st, 1892.

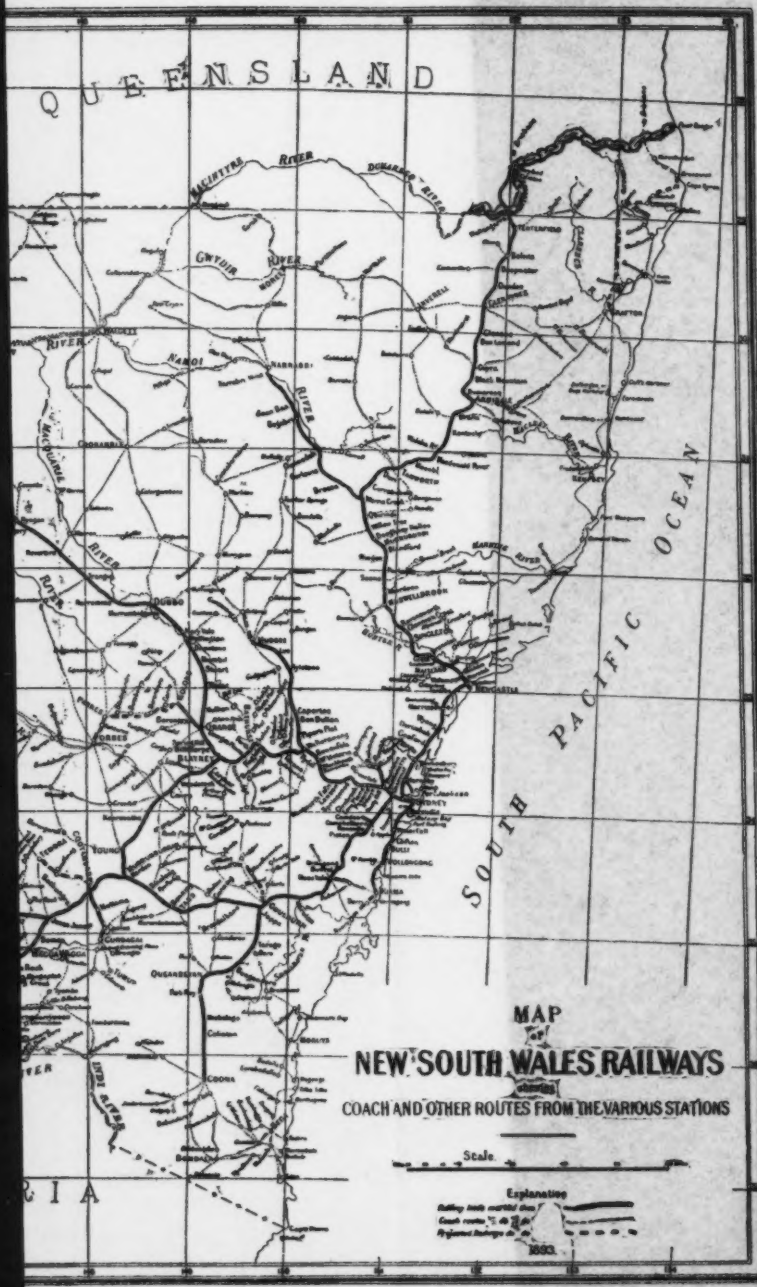
TEMENT.

	Gross Earnings.			Working expenses.	Net earnings.	Gross earnings per train-mile.	Working expenses per train-mile.	Percentage of working expenses to earnings.
al.	Coaching.	Goods and live stock.	Total.					
						Pence.	Pence.	
3 125‡	£35 130 906	£43 230 717	£81 860 607 (1)	£45 144 778	£36 715 829	58.00(2)	33.48	55
7 000	64 549 893	149 738 187	219 557 460 (6)	149 340 000	70 217 460	73.34	49.88	68
0 000	17 320 822	44 634 427	66 618 547 (7)	33 991 783	32 626 764	80.01	45.46	51
5 096	1 189 231	1 918 065	3 107 296	1 914 252	1 943 044	89.25	54.98	61.60
7 677	1 644 315	1 450 807	3 095 12	2 138 139	956 983	62.91	43.45	69.08
1 120	348 199	704 337	1 052 536	639 502	413 034	63.69	38.70	60.76
3 286	349 421	863 869	1 213 290	652 941	560 349	69.69	37.50	53.82
8 694	109 888	59 162	169 050	147 944	21 106	44.64	39.07	87.51
0 489	406 412	709 020	1 115 432	706 517	408 915	88.75	56.32	63.34
0 165	4 846 101	9 755 073	15 025 174 (4)	7 064 904	7 960 270	59.31	27.89	47.02
0 070	86 528	187 176	276 827 (5)	121 966	154 861	96.30	42.45	44.45
3 565	2 060 264	3 641 183	5 701 447	3 378 561	2 322 886	55.29	32.77	59.14

ains. (1) Includes £3 498 974 not shown in coaching and goods traffic. (2) Exclusive of miscellaneous
ides £3 123 miscellaneous. (6) Includes £5 269 380 for miscellaneous service. (7) Includes £4 663 298

um, is for the year ending December 31st, 1891; that for New South Wales, Victoria, Queensland and
, 1892.


COLONY OF QUE
SOUTH AUSTRALIA
COLONY OF VICTORIA
DARLING RIVER
MURRUMBIDGEE RIVER
MURRAY OR HUME RIVER
LACHLAN
MACQUARIE RIVER
BOGAN RIVER
WARREGO RIVER
NAMOI RIVER
GWYDIR RIVER
CASTLEREAGH RIVER
MACINTYRE RIVER
CONDAMINE
BALONNE
WARREGO
NARRAN
BOURKE
WALGETT
COONAMBLE
COOLAH
GUNNEDAH
TAMWORTH
NARRABRI
COONABARABRAN
DUBBO
WELLINGTON
MUDGEE
GULGONG
MOREE
GOONDIWINDI
TOOWOOMBA
DALBY
CHINCHILLA
ROMA
MITCHELL
SURAT
WARWICK
STANTHORPE
TENTERFIELD
GLEN INNES
INVERELL
ARMIDALE
URALLA
TAMWORTH
QUIRINDI
SCONE
MUSWELLBROOK
MAITLAND
NEWCASTLE
CESSNOCK
SINGLETON
PATERSON
DENILIQUIN
ECHUCA
KERANG
SWAN HILL
DONALD
HORSHAM
STAWELL
BALLARAT
CASTLEMAINE
BENDIGO
KYNETON
SEYMOUR
ALEXANDRA
YARRAWONGA
ALBURY
WODONGA
BEECHWORTH
WANGARATTA
BENALLA
YEA
HEALESVILLE
MELBOURNE
GEELONG
WERRIBEE
SORRENTO
PORTLAND
HAMILTON
CASTERTON
MOUNT GAMBIER
KINGSTON
MILLICENT
NARACOORTE
PENOLA
MURRAY BRIDGE
GOOLWA
VICTOR HARBOR
ADELAIDE
GAWLER
KAPUNDA
CLARE
PORT WAKEFIELD
PORT ADELAIDE
PORT PIRIE
PORT AUGUSTA
PORT LINCOLN
WHYALLA
KADINA
WALLAROO
MOONTA
MINLATON
YORKE PENINSULA
KANGAROO ISLAND
MURRAY MOUTH
MURRAY OR HUME RIVER
MURRAY OR BURNE RIVER
RIVER TORRENS


QUEENSLAND
MACINTYRE RIVER
DUMARESQ RIVER
GWYDIR RIVER
NAMOI
NAMOI RIVER
MACQUARIE RIVER
DARLING RIVER
CLARENCE
SOUTH PACIFIC OCEAN
NEWCASTLE
SYDNEY
GOULBURN
ALBURY
MAP
OF THE
NEW SOUTH WALES RAILWAYS
SHOWING
COACH AND OTHER ROUTES FROM THE VARIOUS STATIONS
Scale
Explanation
1883.

outside the car for connecting and disconnecting the currents. The effective capacity of each battery is 113 ampère-hours; and they weigh 530 lbs., or, if their cases are included, 860 lbs. The lamps are fitted with brilliantly white-enameled reflectors, fitting into the ordinary oil lamp globes. The covers are so arranged as to permit oil lamps to be substituted for electric if required. In the trials it was ascertained that the electric lamps were a cheaper means of illumination than the oil. For the first named, with an intensity of 10 candles, the cost including installation, maintenance, etc., was 1 penny, less $\frac{1}{10}$, for 3 lamp-hours. With oil giving 7 C. P. it was the same sum for 2½ lamp-hours. A number of cars are now fully equipped and will be run in the express trains between Paris and Lille, but it is expected that oil will be gradually supplanted by the electric lighting in other trains of the same company. The figures as to cost require confirmation.

Comparative Statement of Railway Workings.—In looking at the statement, it will be seen that as regards mileage the United States takes first place, Germany second, and the United Kingdom third. America ranks first in goods tonnage, train mileage and earnings, the United Kingdom second, and Germany, considering her mileage and density of population, an indifferent third. In the earnings per train-mile, Germany takes the lead with 80.01 pence, the United States follow with 73.34 pence, and the United Kingdom third with 58 pence. But in the working expenses per train-mile she ranks lowest with 33.48 pence, then comes Germany with 45.46 pence, and the United States with 49.88 pence. Germany shows lowest in the percentage of working expenses to gross earnings, but it must be borne in mind that salaries and wages—important factors in railway working, especially when the number of persons employed runs into hundreds of thousands—are far higher in America and England, and that if the same rates were paid in Germany the working expenses would not show to such advantage. As regards the Australian colonies, Victoria takes a decided lead in the number of passengers carried, but this is entirely due to the purely suburban railways, whose place is taken by tramways in Sydney. New South Wales takes first place in goods tonnage, and in gross and net earnings; but in working expenses per train-mile, and the percentage of working expenses to gross earnings, South Australia shows to the best advantage. It must, however, not be for-

gotten that in New South Wales and Queensland, the whole of the inland traffic has to be worked over high mountain ranges which considerably increases the cost of working. India and Ceylon show the lowest percentage of working expenses to earnings, but this is easily explained by the extremely low rates of wages paid in these countries.

In the following table a comparative statement of railway workings in New South Wales for the years 1857–92 is given:

	1857.	1892.
Population of the colony	283 000	1 182 500
Miles of railway open	40	2 359
Persons to each mile of line	7 075	501
Passengers carried	329 019	19 918 916
Journeys per head of population	1.16	16.85
Tonnage of goods	20 847	4 296 713
Tons carried per head of population	.074	3.634

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

615.

(Vol. XXIX.—August, 1893.)

RAILROADS IN THE REPUBLIC OF MEXICO IN 1893.

By E. PRIETO BASAVE, M. Association of Engineers and Architects of Mexico.

Translated from the Spanish by FOSTER CROWELL, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

It is proposed simply to present for consideration various local peculiarities of this country in their relation to the construction and exploitation of railroads; to describe briefly, so far as possible, the difficulties with which they had to contend, and to explain how far those difficulties have been overcome; and, finally, to study the remarkable development which in such a short time has brought within reach of all this means of communication, which was entirely unknown in Mexico 30 years ago.

It is intended also to explain, as fully as the limits of this paper will permit, the results which have been obtained from the introduction of

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

railroads into Mexico, forming an exposition of the progressive increase of traffic in the regions that are now traversed by them, due to the abundant resources which Nature has lavished upon the country, inviting the construction of more railroads in connection with the present terminals, and in other exploitation. It is believed that when what has been undertaken is finished we shall be able to develop the entire country and reward those who come to Mexico, not blindly, like the early builders of railroads, but seeking to invest their capital upon a firm and secure basis, whether contemplating the construction of new roads or the valuable agricultural, mercantile and industrial enterprises which result from them.

About the year 1824 attention was first turned in this country to the necessity of more comprehensive ways of communication to bring into contact the remote regions, not only for meeting the requirements from town to town, but with a general object.

At that time the Government issued its first decree authorizing a contract for the canalization of the Isthmus of Tehuantepec, by means of which both oceans were to be united in one, and Mexico was to become the highway for the traffic of the world.

But difficulties ensued resulting from political causes. It is truly said that the Government at that time was not even powerful enough to insist on its own ideas, and could not protect either the National funds or foreign capitalists seeking to venture their means in enterprises which would be very productive if carried to completion, but who found it very difficult to establish themselves in a country just beginning to form itself. It became necessary to abandon the proper ideals possible in a consolidated nation and to turn attention to the establishment of carriage roads, to which the people were more accustomed, and which seemed to accord with the colonial condition, notwithstanding their narrow possibilities. In pursuance of this policy a decree was issued at that time authorizing the construction of a wagon road from Coazacoalcos to the Pacific as a substitute for the canal project; also, for various other wagon roads, particularly from the city of Mexico to Vera Cruz. Little was done in this direction then, notwithstanding the appropriations made annually for accomplishing the object, the truth being that these were too small for the importance and the number of roads which were necessary. It also happened, moreover, that these insignificant sums were diverted from their objects

and employed for war purposes and in sustaining the governments which succeeded one another with excessive rapidity. For the same reason during this epoch, the maintenance of the old cart roads in condition even for laborious and slow passage, could scarcely be assured. This went on for a period of nearly 50 years employed in granting and withdrawing concessions for constructing railroads, among which figure at the head of the list the Tehuantepec, the Vera Cruz and Mexico and the Northern Pacific, by means of which the country was able to really reap the benefits of the first important line of this sort, that from Vera Cruz to Mexico, opened early in 1873.

It might well be thought, when we consider the topographical difficulties of these first lines which are greater than occur in any other location presented in our country, the refinement which had ensued in the political organization, and the confidence begotten among foreign merchants as to the value of agricultural and mineral elements which we would be able to produce by the new enterprises, that the construction of the rest of the projected railroads would then have been hastened, and that in a brief time we should have developed an extended system, sufficient to bring into action the natural resources of the Republic which had lain dormant for lack of easy communication and exchange. But it did not turn out so; new obstacles appeared, although in smaller numbers, to paralyze the construction of new lines, and not until 1880 can it be said that the formation of the Mexican railroad system began with real activity; since then the progress has been extraordinarily rapid and thorough, so that at the end of the 12 years ending in 1892, 10 283 km. (6 389 miles) of railroad had been built in these regions, with prospects of extension, and by the companies already in the field, who announce that as the conditions develop they will place their lines in exploitation.

In the map attached to this memoir (Plate I), all the lines may be found and they are here enumerated.

TABLE No. 1.

MEXICAN RAILROADS.

	Length of line. Kilometers.
Mexican Railway Company (Limited):	
Mexico to Vera Cruz and branches to Puebla and Pachuca	616

	Length of line. Kilometers.
Mexican National Railroad Company:	
Mexico to Laredo and branches from Acambaro to Patzcuaro, Matamoros to S. Miguel, and Mexico to Salto	1 700
National Construction Company:	
Zacatecas to Ojo Caliente and Manzanillo to Colima....	143
Mexican Interoceanic Railroad Company:	
Mexico to Vera Cruz, with branches from Mexico to Jojutla, from Puebla to Matamoros, Yzucar and Vireyes to S. Juan de los Llamos.....	816
Merida and Progreso Railroad Company:	
Merida to Progreso.....	36
Merida and Peto Railroad Company:	
Merida to Akil.....	99
Mexican Central Railroad Company:	
Mexico to Paso del Norte and Aguas Calientes to Tampico, with branches from Yrapuato to Guadalajara, from Silao to Guanajuato, and from Tula to Pachuca.	2 991
Sonora Railroad Company:	
Guaymas to Nagales.....	422
Hidalgo and Northeastern Railroad Company:	
Mexico towards Tulaneingo and branches to Pachuca and Yrolo.....	190
Sinaloa and Durango Railroad Company:	
Altata to Culiacan.....	62
St. Andres and Chalchicomula Railroad Company:	
S. Andres to Chalchicomula.....	10
Orizaba and Yngenio Railroad Company.....	8
Merida, Valladolid and Progreso Railroad Company:	
Merida to Cansahcab and from Progreso to Conkal.....	97
Tlalmanalco and Chalco Railroad Company:	
Chalco to Amecamua.....	27
Merida and Campeche Railroad Company:	
Merida to Mancanie, and from Campeche to Pomuch....	118
Santa Ana and Flaxcala Railroad Company.....	8
Tehuacan and La Esperanza Railroad Company.....	50
Vera Cruz, Alvarado, Anton Lizardo and Isthmus of Tehuantepec Railroad Company:	
Vera Cruz to Alvarado.....	

	Length of line. Kilometers.
Mexican International Railroad Company:	
Porfirio Diaz to Durango, with branches from Sabinas to Hondo, Hornosa to St. Pedro, and Pedricena to Velardena	914
Toluca and San Juan de las Huertas Railroad Company:	
Toluca to San Juan	16
Cardenas and Rio Grijalva Railroad Company	8
Merida and Yzamal Railroad Company	67
San Juan Bautista and Carrizal Railroad Company:	
San Juan to Altasta	4
Potrero, Cedral, Vanegas and Rio Verde Railroad Company:	
Vanegas to Matehuala and branch from Potrero	58
Monterey and Mexican Gulf Railroad Company:	
Venadito to Tampico	623
Yxtacalco and Mexicaltzingo Railroad Company	20
Puebla Industrial Railroad Company	16
Tecolutla and Espinal Railroad Company	4
Cordoba and Tuxtepec Railroad Company:	
Cordoba to Motzorongo	41
Mexican Northern Railroad Company:	
Escalon to Sierramojada	125
Salamanca and Santiago Valley Railroad Company:	
Salamanca to Jaral	36
S. Marcos and Nautla Railroad Company:	
S. Marcos to Huitzitzitlapan	66
Michoacan and Pacific Railroad Company:	
Maravatio to Ocampo and branch from Angangueo	53
Mexican Southern Railroad Company:	
Puebla to Oaxaca	367
Tonala and Frontera Railroad Company:	
Tonala to Puerta and extension to Frontera	69
Valley Railroad Company	20
Monte Alto Railroad Company	10
Matamoros and Acapulco Railroad Company:	
Matamoros to Tlancualpican	40
Tehuantepec National Railroad Company	240
Marquis and Zimapan Railroad Company	23
Total (6 389 miles)	10 283

The great rapidity with which in this short period so many lines of railroad have been constructed is due to many causes, which have united to produce such a brilliant result; in the first place, the peace of the country, interrupted beforetimes with such frequency, has been unalterably preserved in these last years, so as to maintain the credit of the Government and induce foreign capitalists to come and establish themselves in our country; secondly, the Government, understanding the absolute necessity of means of communication, offered to these enterprises the greatest possible facility, assisting nearly all of them with liberal grants which have been punctually paid.

In previous times the Mexican government, fearful of endangering the public revenue, and perhaps not convinced of the potency of the railroads as a factor in production, extended such meager advantages to the contractors, that all the projects failed utterly. So it went on, as before stated, during 50 years, and it was only possible to change this condition of affairs by assuring peace in the first place, and after that by making great efforts and sacrifices to assist the companies, which efforts were not long in being repaid by the development of traffic and the bringing into action of rich places by means of the railroads as soon as they began to be operated.

In instituting certain comparisons which will appear presently, it is not desired that this country should appear in competition in any manner with the foremost nation in railroad matters; that would be an absurd pretension and improper in a conscientious and serious study; but by comparison it is believed that in none of the very small nations has such rapid impulse been given to railroad construction as in Mexico, the fact being that, while in the United States during the first 20 years of railroad building (1830 to 1850), 12 000 km. (7 456 miles) were built, in Mexico during an equal period of time (from 1872 to 1892) more than 10 000 km. were constructed. If this model could be followed in the coming 20 years, 100 000 km. could be completed, as was done in the United States from 1850 to 1870; or if not, then less than the one-fourth part of them, which would correspond proportionately to the territorial extension; that is, 25 000 km. would have to be acquired, to complete the system already projected, the elements of which will be given in the following pages of this paper. They are submitted for the information of those persons who care to cast their eyes over them, on the accompanying map, where the lines to be con-

structed and which have been consented to by the Government are shown.

In most cases they have been legalized by the community in the hope of being placed in execution at the end of the universal crisis which has oppressed the markets, both native and foreign; when this is over they will proceed without delay. By the time the great World's Fair in Chicago comes to an end, this troublesome situation should be past. Surely the concourse of the highest in all branches of human knowledge which will there unite and join in a common interest, proclaiming ideas, should, we believe, have for a result the disappearance of the obstacles which for two or three years, over all that portion of the globe, have stood in the way of commercial and industrial progress in the Spanish-American nations.

With the object of giving a fair view of the development and increasing progressive production which have attended the railroads since the line from Mexico to Vera Cruz was opened, the writer has set forth the facts in the most concise and clear form possible, arranging them in a table so as to see in relief the gain that each new line has brought to the country, enabling us to appreciate by the series this important truth: "So great is the power of production of railroads, that whenever competition is established between two separate enterprises in the same region, or in analogous zones, the new line, instead of diminishing the entries of the older, increases them considerably"; confirming in this manner a principle recognized in all civilized countries in which railroads have been properly and wisely established, that these elements are creators of wealth. These results, although very imperfect in Mexico, notwithstanding the great impulse given to railroads in late years, demonstrate the correctness of the aphorism by an English statesman who says: "Allow the country to make the railroad, and the railroad will make the country"; but only when our railroad system is perfected will this be fully realized; when we have woven the important, the fundamental, threads which are wanting and which must be built, in order to maintain regular pecuniary relations with the markets of the United States and Europe, then there will be a great gestation of wealth, and the activity already begun shall be in full growth, and Mexico will be able to utilize to its own profit, and the profit of the entire world, its advantageous geographical position and unusual stores of unbounded wealth.

TABLE No. 2.

Mexican Railroads.—Statistics of Operation.

Years.	Mexico and Vera Cruz Railroad.			Mexican Interoceanic Railroad.			Mexican Central Railway.			Mexican National Railroad.		
	Passengers.	Tons, freight.	Gross earnings.	Passengers.	Tons, freight.	Gross earnings.	Passengers.	Tons, freight.	Gross earnings.	Passengers	Tons, freight.	Gross earnings.
1873..	476 287	150 473	$1 830 910*	.....	.....	.....	.....	.....	.....	247 547	.....	$17 425
1874..	459 601	121 935	2 354 845	.....	.....	.....	.....	.....	.....	584 075	298	40 744
1875..	267 776	136 632	2 446 555	.....	.....	.....	.....	.....	.....	486 788	221	43 248
1876..	245 675	132 216	2 221 736	.....	.....	.....	.....	.....	.....	486 000	698	44 146
1877 .	300 591	158 537	2 788 986	.....	.....	.....	.....	.....	.....	565 572	346	53 035
1878..	279 893	169 287	2 958 832	.....	.....	.....	.....	.....	.....	529 333	3 209	75 039
1879..	293 179	190 908	3 340 724	.....	.....	.....	.....	.....	.....	535 806	8 102	89 606
1880..	323 088	219 930	3 791 284	228 053	11 431	$101 793	.....	.....	.....	466 897	18 191	133 489
1881..	331 749	278 942	5 020 784	367 116	49 942	264 618	303 543	7 012	$95 683	903 049	26 234	171 772
1882..	385 621	333 979	6 092 326	411 090	53 382	369 250	491 985	202 304	1 732 713	900 855	105 549	454 853
1883..	409 098	373 389	5 826 276	406 016	56 822	579 956	653 669	167 356	3 603 736	1 071 835	140 185	707 935
1884..	389 421	236 030	3 847 374	634 306	131 385	655 122	761 687	190 423	3 774 591	878 878	254 804	1 260 740
1885..	377 512	246 169	3 416 650	606 510	167 970	676 578	694 894	331 700	3 595 388	839 573	177 679	1 296 114
1886..	367 260	266 432	3 318 361	569 421	148 001	706 818	769 655	255 027	3 940 275	891 711	232 661	1 556 378
1887..	380 153	301 185	3 797 215	621 295	174 194	809 845	797 693	356 448	4 973 102	884 541	307 435	1 658 470
1888..	393 679	351 070	4 046 577	673 169	200 386	912 872	756 560	519 261	5 892 564	907 113	370 300	2 572 599
1889..	444 149	391 627	4 277 685	596 812	190 902	982 411	683 147	576 324	6 517 929	929 685	433 166	3 486 728
1890..	502 139	443 794	4 266 999	657 616	288 836	1 537 106	736 730	694 966	6 699 384	937 527	487 598	3 561 987
1891..	620 988	464 123	4 071 950	795 625	282 311	1 633 248	753 276	1 005 417	7 679 507	998 617	515 164	4 052 842
1892..	No returns given.											

* Mexican currency.

Having considered the exposition of the development unfolded by the railroads, the writer will proceed to study the parts of the system yet to be built, with the purpose, as far as the limits of the paper will permit, of completing the subject.

It will be sufficient to take into consideration only the principal lines in order to demonstrate the annual increase due to the beneficent influence which the new lines have exercised upon those established earlier.

A superficial inspection of the foregoing table is enough to convince one of the rapid advance, not only in proportion to the augmented length of line, but in an increasing ratio which has attended the business and earnings of the four principal enterprises of the country. In fact, the Mexican Railroad Company which, with the exception of its subordinate line from Ometusca to Pachuca, has not increased its kilometrage, has increased its earnings from $1 800 000 to $4 000 000 during the period under consideration, a most excellent showing in view of the very notable circumstance that, during the year 1880, in which the Interoceanic Company began operation, there was a substantial increase in the earnings of the Mexican Company.

With regard to the Mexican Central, it is quite apparent that its competitor, the Mexican National, very far from injuring it by the establishment of its line to Laredo, has stimulated it, both lines showing notable increase in annual entries.

Neither did they suffer in the dreadful crisis produced in the last years by the failure of the crops, the low price of silver, the bad state of the public health in all the more thickly populated places of the country, and the rest of the circumstances which impoverished the citizens and interfered with business; so that, despite the obstacles which, taken separately, tended to diminish the earnings of the railroad, they were able to push forward with great strength everywhere for so long a time, and the growing railroad system has kept up its business and in operation in all the development of the system, extending over the whole region of country, and facilitating communication, both intercontinental and interoceanic.

According to the data received from original sources for the year 1891, the traffic on the Mexican railroads amounted to from 5 000 000 to 6 000 000 of passengers and more than 3 000 000 tons of freight, the gross earnings being $20 000 000 (*pesos*).

At the time of writing it is not possible to assemble the data for the year just past, for there has been no minister in the office of Secretary of Communications and Public Works; but if we take as basis the proportionate increase in the earnings year by year, and consider that in 1892 there have been put into operation the important lines from Torrean to Durango, and from Tecomavaca to Oaxaca, there will be no risk in assuming for that year a total earning of $25 000 000 (*pesos*) for all the railroads.

Nearly $200 000 000 (*pesos*) have been expended in the construction of railroads up to this time, not including the line across the Isthmus of Tehuantepec, which has had so many different estimates and undergone so many changes of plan that it is not easy to give even an approximate idea of its cost. But, however, we repeat, those already opened to operation, wholly or in part, not taking into account the estimates for the rest of the lines hereafter, have cost $200 000 000, approximately. Of this the Government has advanced to the companies nearly $76 000 000, it is said, more than a third part of the whole sum, in form of subventions, which vary from $3 500 to $9 500 per kilometer ($5 600 to $15 300 per mile), according to class and condition of each road.

In three cases only among the more important lines the Government has adopted another system of subvention; these are the Mexican and Vera Cruz R. R., for which, it is understood, a fund of $8 000 000 (*pesos*) was appropriated out of the maritime duties, in a certain percentage of the entries amounting to about $560 000 annually; also the Puebla and Oaxaca, and the Matamoros, Yzucar and Acapulco lines, which drew from the Government 8% interest on the cost of the road when constructed at the rate of $30 000 per kilometer ($48 000 per mile). This value, this almost unheard-of subvention, serves to demonstrate the difference at the present time, when the railroad system meets with general encouragement, and in which the Government has adopted the principle in general of granting no more subventions; only the great necessity of pushing forward the work of the companies which are building lines to the Pacific has obliged it to break the rule and to assist in a powerful manner those who have appealed to it to complete the system.

In a general view of the business from ocean to ocean, and we may say from one end of the Republic to the other, the companies which

are projecting new lines have gone about it with proper energy and after taking into account the business to be secured, to which they will give greater facility, and what capital is required.

The experience acquired upon previous studies and surveys by the Mexican engineers has given them an aptitude for verifying, in the most difficult locations, the economies, in time and money, of construction. The price of labor, always very low in this country, has been cheapened still more since the peons and Mexican laborers have become skilled in the work of which at first they knew nothing; the facility and economy in the transportation of materials, both native and foreign, which have been carried for ingots, instead of paying dearly for transportation, as was formerly the case; and, lastly, all the essentials for the exploitation are met and can be utilized anywhere, presenting to the companies, as we have said, a wide field for basing their calculation in a very positive degree, which enables them to do work with great success without assistance from the public.

We may truly say that we have entered upon the second era of railroad building, in that we are able to establish them without subventions with assured success to sustain their cost and meet interest charges on the capital invested. The present improving condition of material productions, which has been proved to exist in most cases, is a guarantee to those who hereafter may come here, to engage in any enterprise, that to secure the expected profit it is only necessary to analyze the business thoroughly, not to waste all the funds in bad management and not to falter on account of questions of expediency for the shareholders.

The third epoch for the construction of railroads is perhaps already late in arriving, but will follow the first two; and when that time comes such enterprises will be developed as will pay for their establishment in local interests. These will be chiefly small branches to serve as feeders for the main roads, their importance not being great as regards distance covered, but the business they will induce will be very extensive, it being impossible to fix the limit to the local necessities which will arise and which invariably adjust themselves to the measure of the business activities.

It is now in order to make a brief reference to the financial condition of the four principal railroads we have considered, with the object of having it serve as a study for those who may come to renew railroad building in this country. During the year 1891, which is the last one

for which we have the figures, the percentages of net earnings were as follows:

Mexican Railway	42%	of gross earnings.
Interoceanic Railroad	31%	" "
Mexican Central Railway	33%	" "
Mexican National Railroad	30%	" "

From this it is evident that the Mexican Railway, notwithstanding its excessive construction account, must possess an excellent management, and in turn enjoy excellent opportunities to secure business, the operating expenses being for these two reasons relatively small.

The Mexican Central Railway, which is operated in a well-chosen district, and for the most part with few accidents, unites to these conditions a well-ordered administration and the heavy subventions which it has received, amounting to the sum of $28 000 000.

The Interoceanic Railroad, constructed at a low cost and with good subventions, has been able to sustain its heavy maintenance charges, and to counteract some of the defects of its administration which have consumed a large part of its earnings, and may be said not to have really suffered from these defects, for it is the railroad which earns the largest rate of interest annually.

Lastly, the Mexican National Railroad, which has an enormously high construction account while it did not get such strong subventions, and is not very well managed, consumed on this account* 70% of its gross earnings, which are not very abundant; of the four, in the writer's judgment, it is located in the most disadvantageous position.

The fact is, that while the Mexican Railway has paid between 6 and 7% per annum, the Interoceanic between 8 and 9%, and the Central 13 to 14%, the Mexican National has only realized about 4 per cent.

Doubtless the low earnings of the last-named road will go on increasing from year to year, but at the present time it is paying the tribute due especially to its wasteful construction, for, notwithstanding its being a narrow-gauge road, it has cost 50% more per kilometer than the Central.

In concluding this memoir the writer will occupy himself with the supplementary railroad system as actually projected in connection with the several great lines and for perfecting local communication.

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* The author omits to mention here that the Mexican National is narrow-gauge, while the other three are standard gauge; farther on, however, he refers to the first fact.—*Translator.*

Many lines have been granted, the greater part with subventions, awaiting improvement in the financial condition to be built; the developments of these lines, which are given below in Table No. 3, are only approximate, inasmuch that generally they are not yet finally located.

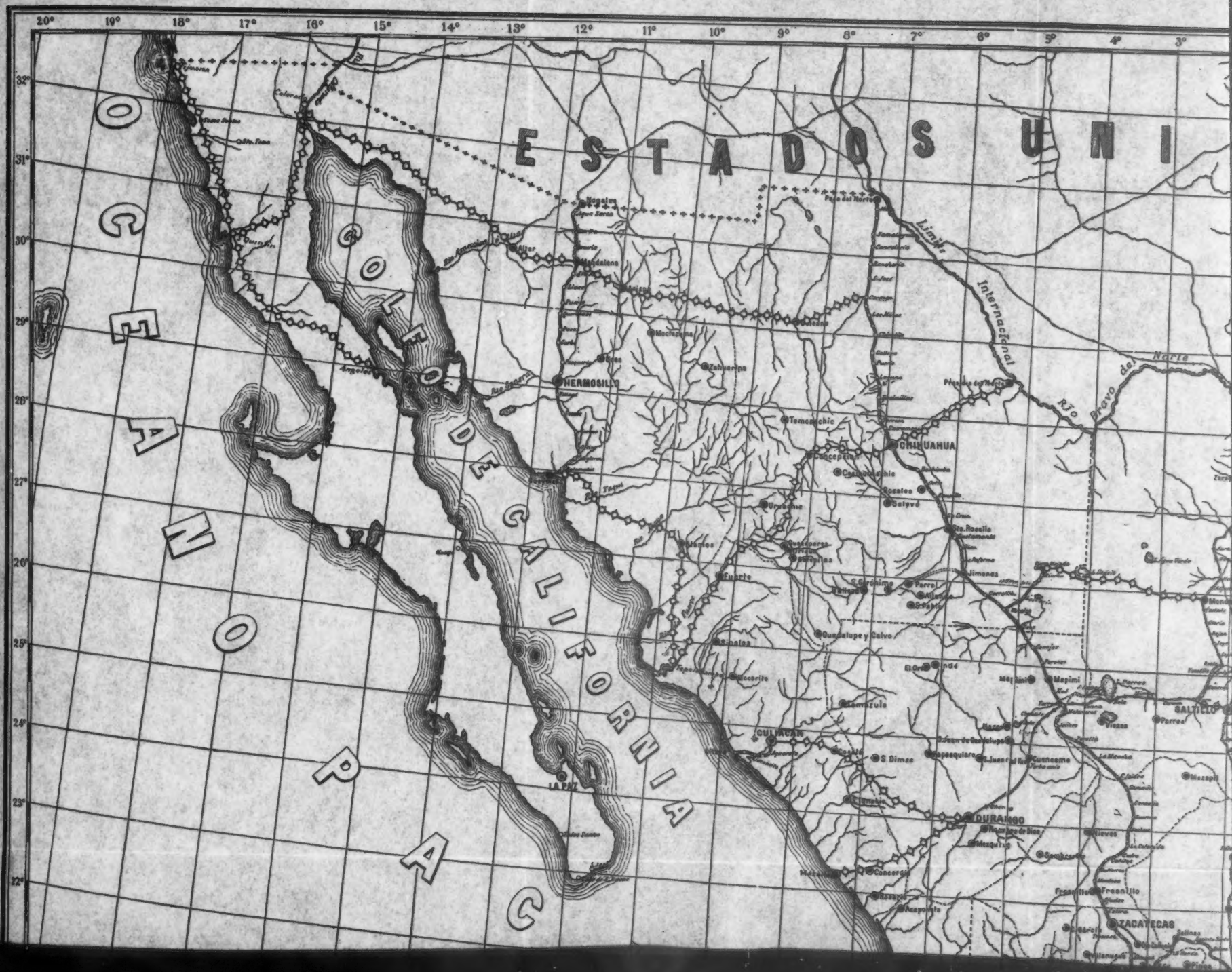
In the accompanying map the probable locations of the lines named are shown.

TABLE No. 3.

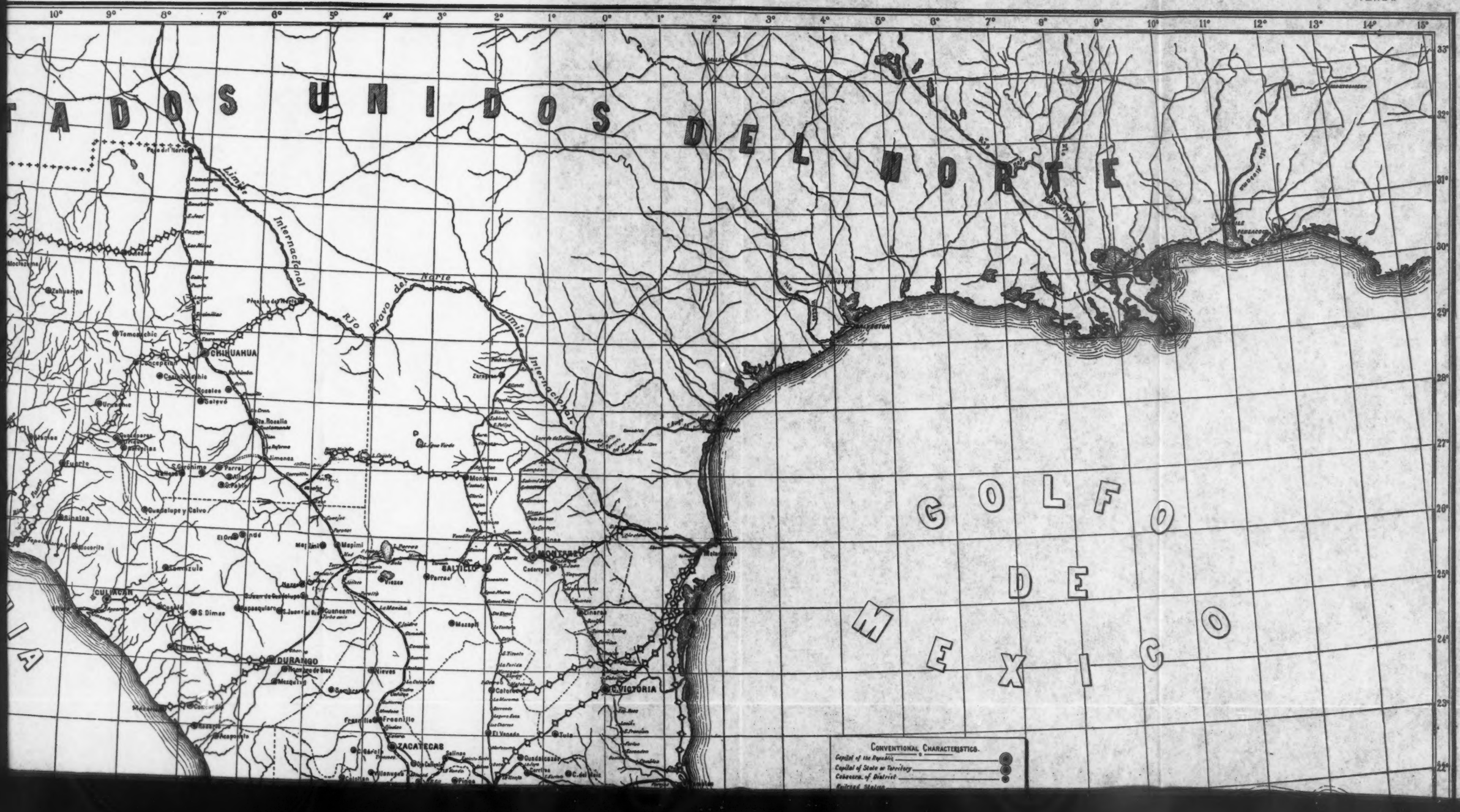
MEXICAN SUPPLEMENTARY LINES.

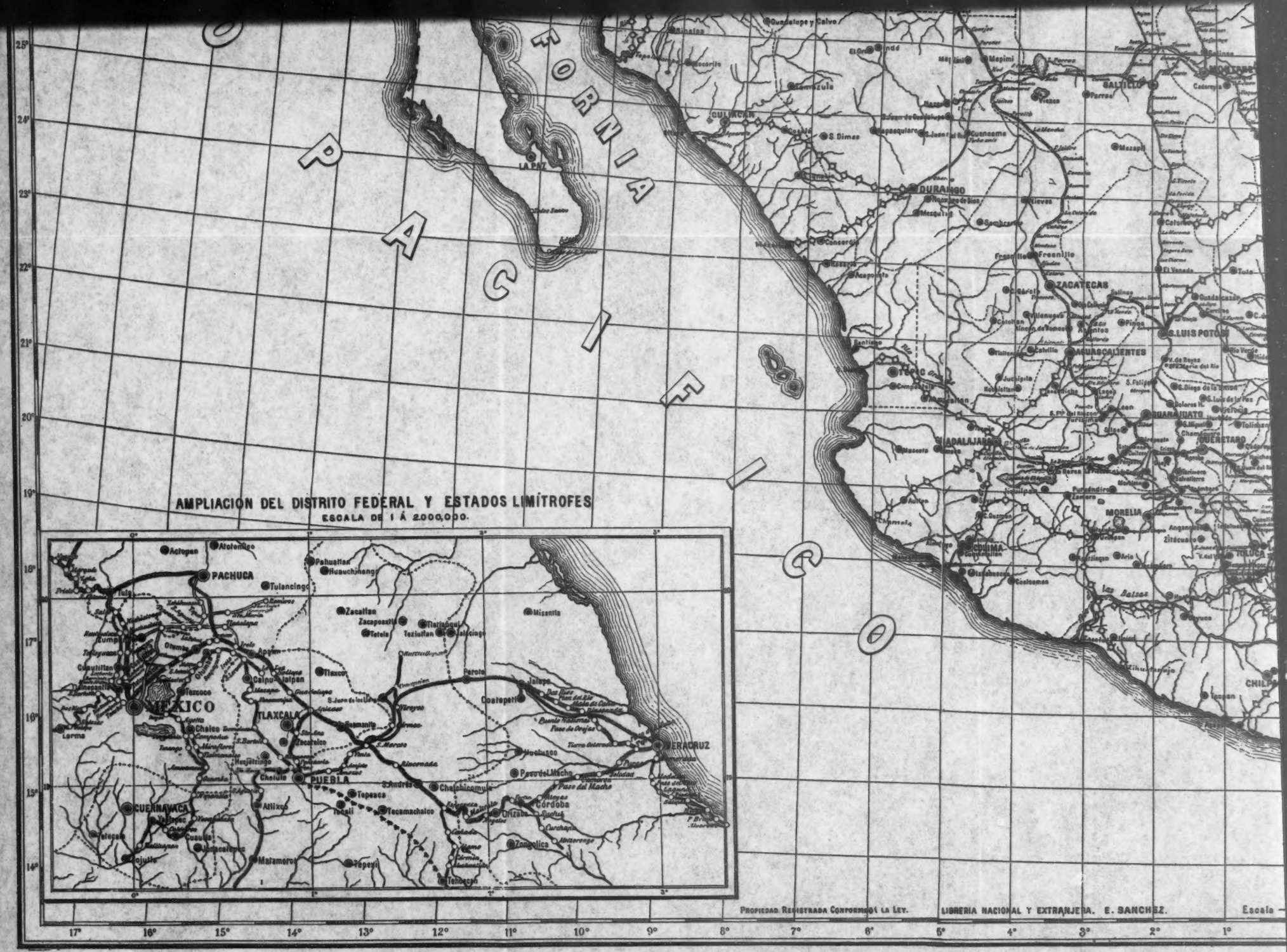
	Length. Kilometers.
Hidalgo and North Eastern Railroad:	
Los Romeros to Tuxpan	250
Alvarado Railroad Company:	
Alvarado to Tehuantepec	250
Mexican Interoceanic:	
Jojutla to Amacusac	30
Sinaloa and Durango Railroad Company:	
Culiacan to Durango	450
Mexican Central Railway Company:	
Guadalajara to S. Blas	350
Mexican National Railroad Company:	
S. Miguel to Monterey or to Laredo 250	
Morelia to Colima 400	
——	650
Merida and Peto Railroad Company:	
Tekan to Peto	60
Merida and Valladolid:	
Cansahcab to Valladolid	125
Merida and Campeche:	
Hecelchakan to Mazatlan	60
Mexican International Railroad Company:	
Durango to Mazatlan	300
San Marco and Nautla Railway Company:	
Huitzitzitlapan to Nautla	140
San Benito and Tapachula Railroad Company:	
San Benito to Tapachula 60	
Tapachula to Tehuantepec Railway 560	
——	620

	Length. Kilometers.
Mexican Southern Railway Company:	
Oaxaca to Tehuantepec	240
Mexican Pacific Railway Company:	
Mexico to Cuernavaca and Palizada	450
Tonala and Frontera Railroad Company:	
Taltan to Frontera	360
California Bay Railroad Company:	
San Quintin to Rio Colorado	300
San Quintin to Tiguana	300
San Quintin to Los Angeles Bay	420
Rio Colorado to Magdalena	630
Magdalena to Mexican Central Railway	620
	2 270
Sonora, Sinaloa and Chihuahua Railroad Company:	
Guaymas, via Alamos to Topolobampo	570
Topolobampo via Fuerte to Ciudad Guerrero	510
	1 080
Sierra Mojada and International Railroad Company	450
Zamora and Zihuatanejo Railroad Company	400
Cordoba and Tuxtepec Railroad Company	130
Pachuca and Tampico Railroad Company:	
Angangueo to Yguala	240
National Railroad Company of Tehuantepec:	
Intermediate portion	60
Matamoros, Yzucar and Acapulco Railroad Company:	
Tlancualpicana to Acapulco	340
Matamoros and Matehuala Railroad Company	600
Matamoros and San Luis Potosi Railroad Company	800
Mazatlan and Camargo Railroad Company:	
Topolobampo to Presidio	930
Aguas Calientes, Guadalajara and Chamela Railroad Company	585
Continental Railroad Company:	
Matamoros to Tuxpan	825
Tuxpan to Tehuantepec Railroad	675
Tuxpan to Mexico	375
	1 875


ESTADOS UNI
OCEANO PAC
GOLFO DE CALIFORNIA
Límite Internacional
Río Bravo del Norte
HERMOSILLO
CHIHUAHUA
DURANGO
CULIACAN
LA PAZ
SALTILLO
ZACATECAS
Nogales
Guaymas
Mazatlán
Topolobampo
Ojinaga
Piedras Negras
Nuevo Laredo
Matamoros
Tampico
Monterrey
Torreón
Parral
Jiménez
Camargo
Delicias
Cuauhtémoc
Hidalgo del Parral
Guadalupe y Calvo
Sinaloa
Durango
Mapimí
Viesca
Lerdo
Gómez Palacio
Fresnillo
Sombrerete
Nieves
Concepción
Rosales
Satevó
Ojinaga
Urique
Batopilas
Creel
Cerro Azul
Tepehuanes
Mezquital
Nazas
Cuencamé
Peñón Blanco
Río Conchos
Río Nazas
Río Florido
Río Sonora
Río Yaqui
Río Mayo
Río Fuerte
Río Sinaloa
Río Grande
Río Salado
Río Pecos
Río Colorado
Río Gila
Río Concepción
Río Santa María
Río Casas Grandes
Río Papigochic
Río Conchos
Río Florido
Río Nazas
Río Aguanaval
Río Mezquital
Río Presidio
Río Grande
Río Salado
Río Pecos
Río Colorado
Río Gila
Río Concepción
Río Santa María
Río Casas Grandes
Río Papigochic

VOL. XXIX, No. 615.
TRANS. AM. SOC. CIV. ENGRS.
BASAVE ON RAILROADS IN MEXICO.
PLATE I.





Propiedad Registrada Conforme á la Ley.

Libreria Nacional y Extranjera. E. Sanchez.

Escala —

GOLFO DE MEXICO
MAR CARIBE
CENTRO AMÉRICA
CONVENTIONAL CHARACTERISTICS.
Capital of the Republic
Capital of State or Territory
Cabecera of District
Railroad Station
Mexican Central Ry.
Mexican National R. R.
Mexican Interoceanic R.R.
Mexico & Vera-cruz R.R.
Mexican International R.R.
Hidalgo & N.E.R.R.
Mexican Southern R.R.
Monterey & Mexican Gulf R.R.
Morelia & Acambaro R.R.
American (U.S.) Rail Roads
State boundaries
International boundaries
Mexico & Progreso R.R. via S. Ignacio
Merida & Valladolid, with branch to Progreso
Merida & Izamal
Merida & Peto
Merida & Campeche
Railroads projected
DURANGO
ZACATECAS
AGUASCALIENTES
GUADALAJARA
GUANAJUATO
QUERETARO
S.LUIS POTOSI
C. VICTORIA
MONTERREY
MEXICO
PUEBLA
VERACRUZ
MORELIA
COLIMA
OAXACA
CHILPANCINGO
TOLUCA
CAMPECHE
MERIDA
BELIZE
S.CRISTOBAL
Escala — 1: 5.000.000
PROPIEDAD REGISTRADA CONFORME A LA LEY. LIBRERIA NACIONAL Y EXTRANJERA. E. SANCHEZ.
IMP. Y LIT. ESPAÑOLA. MEXICO.

	Length. Kilometers.
The remaining lines of this company have not been determined upon.	
Tula, Zacualtipan and Tuxpan Railroad Company.....	345
Ishmus of Tehuantepec Railroad Company to the Guatemala Foundry.....	570
Saltillo and International Railroad Company:	
Saltillo to Jural.....	75
Toluca and Cuernavaca Railroad Company.....	100
Mexico and Zacatula Railroad Company.....	525
Total (9 994 miles).....	16 085

Some of these concessions have lapsed, but as the greater number of them possess subventions and all are lines with a great future, it is believed that in a short time they will be rehabilitated, inasmuch as at the present time there is a sense of solicitude and a very favorable disposition on the part of the Mexican government to push forward the construction of the railroads which are lacking, though not with such great expenditures as was at first necessary, in which there was always blundering and great waste of money by the companies, who nearly all rushed blindly into enterprises regardless of consequences.

We are able to calculate approximately the additional capital required for the extension of the Mexican railroads in accordance with the above enumeration; $300 000 000 or $400 000 000 will be necessary to cover the system of through lines, and, perhaps, as much more to complete the local roads.

This is not an appropriate moment for believing that all this will be accomplished within a very short time, but we may take comfort for the present, while still in the midst of the economic struggle which preoccupies all nations, that we are able to continue building two or three of the more important lines, bringing us near to the establishing of interoceanic communication, which for many complex reasons has been so long retarded, to the injury of the entire country.

The greatest injury by this delay has been to the western territory, in which are situated such rich and important places as Guadalajara, Morelia, Durango, Oaxaca and many others, where also await facile

communication the numerous, abundant and rich products of the tropics—rice, chocolate, coffee, indigo, fruits of various kinds, valuable woods and many other miscellaneous products—which are being lost for lack of consumers, and which, ere long, will be scientifically cultivated and transported to all the centers of consumption, giving rise to a prosperity of which, perhaps, their owners have as yet formed no conception.

The lines on which construction is now being prosecuted are the Tehuantepec National Railway, which it is said will be completed by the end of the present year, thus realizing a desire which Mexico has cherished for nearly a century; the Matamoros, Yzucar and Acapulco Railroad, which extends through the richest and most productive regions of the States of Puebla and Guerrero; and the Cuernavaca and Pacific Railroad, just started at the capital of the Republic, and which will soon reach the State of Morelos and continue its march towards the Pacific, opening up the riches of the unknown and now neglected, but not the less fertile, lands of Guerrero. The Hidalgo and Northeastern road is also under construction to Tuxpan, and other railroads in Yucatan.

Space is lacking to pursue the discussion of so vast a subject. Scarcely more has been done than to call attention to the leading points of our railroad situation, and perhaps these cursory notes will bring out very little that is useful. In endeavoring to study all the circumstances which more or less directly affect the works already built or those we desire to build, they may, perhaps, have been passed over too superficially, and yet it may be said that it has not been easy to consider them all with the desired care; but the subject is too complex to formulate a good and complete study upon the matter as thoroughly as is necessary, to give a methodical estimate of them all without exceeding the time now available, and yet, without the essential gifts for close study and methodical research, perhaps there may be conveyed, between these lines, something more than the small measure of their apparent value.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XXIX.—August, 1893.)

STUDY UPON RAILROADS TO CONNECT GUADALAJARA WITH THE PACIFIC OCEAN.

By S. V. PASCAL, M. Association of Engineers and Architects of Mexico.

Translated from the Spanish by FOSTER CROWELL, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The study of a railroad line can be divided into two parts which are intimately related to one another, the financial and the technical. The first relates to the probable valuation of the earnings which the line can command, taking as the foundation of its considerations the present traffic between its terminals and, generally, of the territory along its base; the lawful rates it can obtain; the amount of capital that can

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

be secured for the enterprise in question; the profits to be derived; the cost for which, in favorable circumstances, it can be built, and the increased traffic to be developed by the industries and by agriculture at points reached by the line, due to the facility and rapidity of communication afforded.

The second, that is, the technical, belongs to the engineer, embraces exploration of the country for a location, the cost of which shall be the least possible. This problem is truly a difficult one, requiring generally and in all important lines much practice and experience, inasmuch that almost always it must be decided at first sight upon principles which afterwards necessitate profound study.

The comparison of the approximate value of the cost of the line with the provision by the estimated traffic determines whether the study can be adhered to; and, finally, in view of the revised data, the estimate decides the construction of the line.

It should here be stated that, not having the final data of the surveys and estimates for the projected railroads between Guadalajara and either San Blas, Chamela or Manzanillo, the writer proposes, in studying these projects, to advert only to the figures of the traffic as furnished by the Chamber of Commerce of this capital. For the technical information regarding the railroad line to San Blas he is indebted to the kindness of the Chief Engineer, Señor D. Porferio Somelli, and for the data of the lines to Chamela and Manzanillo, respectively, by favor of Chief Engineer Don Carlos Ockon Arronis.

The data furnished by the Chamber of Commerce, in an extended and conscientious report to the State Government, assigns for the movement of merchandise on any one of the three lines of which it treats, 200 000 tons per kilometer, and a like number of passengers. To obtain these figures the Chamber took the amount of annual collections that had been made at the toll houses in the towns along the projected routes, such as Zocoalea, Sayula, C. Guzman, Tepic, Etzatlan, Ahualulca, Ameca, etc., and also the records of the annual agricultural production of Talisco, Colima and Tepic. Such records are the most reliable that could possibly be obtained, for they are derived from the actual traffic and from the official count of the production; they have been taken for the basis of the present study.

In the introduction to the part that relates to the end in view, they say as follows:

"In estimating the freight traffic at an annual average of 200 000 tons, for the least annually, on the lines referred to, we based the subscription on the legal records which are found in the municipal exchange of the capital; those that refer to the traffic have been obtained from the Custom House of Mexicalcingo, which represents the principal part of the freight movement between Guadalajara and the southern part of Talisco, Colima and the Pacific Coast, amounting in the last half year of 1892 to $6 129.83; revenue from tolls upon vehicles and beasts of burden with freight of various kinds entering the city through the custom house; and the traffic of the first six months of the year being greater than of the second, we have deduced the subscription of $12 500 as our estimate for the least annual revenue at that place. At Salida we estimate $10 000, for the road tolls are not so heavy, and we only calculate the produce to be worth $1 per load, which corresponds to a considerable movement, and considering also that the freight pays specific duties, and that the cattle and the like which the railroad would be able to transport pay no duties on entrance, or in passing through the capital, we deduce the total annual freight movement, according to the custom house, amounting upon a conservative estimate to 200 000 tons."

"In calculating the traffic for some of the principal towns of Southern Talisco, which would pay tribute to the railroad at Colima and Manzanillo, and in order to obtain another subscription of reliable data, we looked up the freight movement at C. Guzman, the principal town or cabacera of the ninth canton of the State of Talisco. The results here, according to reliable information from Señor Sullivan, selected by competent persons to speak for the town, amounted to more than 1 200 000 packages of freight of 6 to 8 arrobas (150 to 200 lbs.), approximately, each, in every year of the five years covered by the information; this quantity is equivalent at least to 100 000 tons per kilometer, without including cattle and other animals that will be carried by the railroad.

"The traffic obtainable in the capital of Ojarita del Carmen and Zapopan, representing the major part of that which exists between Guadalajara and the western portion of the State of Talisco, Territory of Tepic, and the States of the extreme western part of the Republic, etc., equals, approximately, that of Mexicalcingo.

"The freight traffic of the city of Tepic, according to figures of bonded merchandise obtained from the custom house there, given me by the illustrious Secretary, Señor Manuel M. Gonzales, was, in the fiscal year of 1891–92, 173 459 packages. Estimates by this officer place the total movement of merchandise at much more than of that which pays duty, because the latter does not include any articles that do not pay port charges. There are many articles which do not pass through the custom house, such as beans and corn, and, according to

persons well known in Tepic, not less than 50 000 bushels of corn enter annually, and the other cereals in proportion.

"It may possibly be that the share of traffic of each capital of territory is unduly large relatively to the remaining towns of this district, among which are contained others as rich and as full of traffic, as Yxtlan, Santiago and Acaponeta; nevertheless, it may still be affirmed with all confidence that this region is a suitable field for the railroad of which we treat, and in a very considerable degree.

"Turning our attention to the present condition of things, in regard to the occupation of this territory by a railroad immediately, we may say that it is almost entirely isolated from the rest of the country, being connected with it only by a road which is almost entirely impassible through neglect; but by means of easy communication this territory may be placed in condition to command both the eastern and western markets of the Republic, and its transformation will be quick and marvelous, for the reason that it is a privileged region and suitable for developing in a high degree a multitude of agricultural and manufacturing industries."

The same may be said respecting the present and future of the cantons of the States of Talisco and Colima, no matter by which route the iron road reaches the Pacific seaboard, for it will bring each of these extensive regions into activity without prejudice to the other; on the contrary, the whole territory will be enabled by means of lateral branches to avail itself of the beneficial effect of the railroads, as was demonstrated in an important technical report rendered recently to the Board of Directors of the Central Railroad.

Besides these factors for appraising the freight traffic existing and to be developed on these lines of railroad, it has been found very convenient to take in connection with them the official records of recent date, which give ready to the hand the agricultural and industrial statistics, etc., in the States of Talisco and Colima and Territory of Tepic. The results are for the most part in favor of there being a railroad from Guadalajara to the Pacific ports, and in effect reproducing what we find given in the "Statistics of the Mexican Republic," by Señor E. Busto, published as an appendix to the Report of Revenue; from them the following figures, giving the principal productions of Talisco, are taken:

Corn	608 410 000 kg.
Beans	20 628 360 "
Wheat	74 310 000 "

Mescal, refined	98 000 barrels.	
Mescal, ordinary	12 397 "	
Rum, from cane	12 320 "	
Palm hats	185 672 pieces.	
Pulque, ordinary	116 250 arrobas.	
Linseed oil	3 650 "	
Vetch	590 520 kg.	
Cotton	2,448 000 "	(Talisco and Tepic.)
Sesame	123 570 "	
Anise seed	93 610 "	
Indigo	9 452 "	
Rice	1 074 360 "	(Talisco and Tepic.)
Barley	2 272 000 "	" "
Cumin	30 054 "	" "
Pepper	5 970 000 "	" "
Chicory	330 860 "	(Talisco.)
Haba beans	862 956 "	
Potatoes	774 860 "	
Masas	19 690 "	
Straw	33 650 000 "	
Beer	16 200 barrels.	
Tobacco	2 422 300 kg.	(Talisco and Tepic.)
Sugar and molasses	2 950 500 "	

Before footing up the total productions of Talisco we must add the product of the manufacturing industries and of mining, cattle-raising, etc., which requires transportation to the State capital, the principal towns of the south, southeast and east of the State of Colima, the Territory of Tepic and to Pacific ports.

Respecting the quantities of the productions, agricultural and other, of the State of Colima, we have taken from the statistics cited the following data of annual productions:

Corn	39 100 000 kg.
Wheat	5 500 000 "
Barley	9 750 000 "
Beans	564 000 "
Cotton	1 500 000 "
Indigo	5 400 "

Rice	1 770 000 kg.
Sugar and molasses	102 000 "
Chocolate	4 250* "
Coffee	300 000 "
Pepper	395 000 "
Tobacco	10 180 "
Vanilla	148 "
Rum, from cane	327 barrels.
Beer	1 236 "
Mescal, ordinary	3 265 "
Straw hats	6 216 pieces.
Wine of coca	1 632 arrobas.
Tolu	9 854 "

In the following exhibit we give the four principal agricultural productions of the Territory of Tepic, according to the same statistics of the Republic:

Corn	138 000 000 kg.
Wheat	14 000 000 "
Beans	3 250 000 "

In respect of the quantity of rice, sugar, tobacco and cotton which are figured among the productions of Talisco before given, they are assumed to be half of the corresponding quantities in the Territory of Tepic.

In the railroads throughout the country which have as great tonnage as in this case, 50% of the gross earnings are consumed in operating, leaving the other 50% as return on the invested capital.

By the projected line from San Blas to Guadalajara the distance is 348 km. (216 miles), and assuming the average rate to be fixed at 4 cents per ton of 1 000 kg. (2 205 lbs.) per kilo. (7 cents per ton-mile) and 2 cents per passenger (3½ cents per passenger-mile), there would be earned annually $4 176 000, of which $2 088 000 would return to the capital invested. The capitalization being at the rate of 10% annually, we obtain the sum of $20 880 000 for the allowable expenditure for the construction of the line of which we are treating.

* This amount is in error; should be between 40 000 and 50 000 kg.—TRANSLATOR.

Similarly on the line to Chamela the distance is 433 km. (269 miles), on which the revenue, calculated in the same manner as before, would allow of a first cost of $25 980 000.

For the Manzanillo line we find analogous results.

The line from San Blas has been examined for the Central Mexican Railway people; from Guadalajara to El Refugio, in a length of 45 km., it has a maximum grade of 1½ per cent. It follows generally the Ameca wagon road, deviating at several points to obtain more uniform gradients. It passes through La Venta, El Reventon, with a small tunnel, Los Lomelines, Huaxtla and El Refugio. At El Refugio it forks, there being two alternates, one by the Sierra de Pajaritos and the other by the Ameca River Valley.

The last would be selected, as it follows the natural water-courses, but for the difficulties which occur, the lowness of the line, and its exposure and very great cost of maintenance.

Beyond El Refugio, until it enters the real cañon of the Ameca River, there are about 51 km. of smooth ground, with light grades and easy construction, save at three or four points of no great importance. The line passes Ameca and follows the right bank of the river. Continuing down the cañon it meets with narrow and difficult defiles, narrow banks which the river frequently overflows, the passage of which in some manner cannot be avoided, and having, in fine, a thousand difficulties before reaching any other town of importance; there we arrive at San José del Conde, having come 104 km. The grade through the cañon does not exceed 1½% until reaching the confluence of the River Ahuacatlan. At this point, following the river bank, it ascends with a 2½% grade for a distance of about 20 km., which continues until arriving near San José del Conde. On this stretch of 104 km. the average cost will run as high as $40 000 per kilometer ($64 500 per mile), because of the heavy works of construction and for defense which are included.

Returning to the alternate location by way of the Pajaritos, which is the one that in the writer's opinion should be adopted, we will continue the description. From El Refugio to San José del Conde it is divided into three distinct sections; the first extending to San Marcos, passing through the villages and towns of Teuchitlan, Ahualulco, Etzatlan and San Marcos, with a development of 53 km. easy grades reaching to 1½% on very short stretches, without much very heavy

work; average cost per kilometer, $20 000 ($32 300 per mile). The second section extends from San Marcos to Ocote, a distance of nearly 50 km., including the passage of the Sierra de Pajaritos. The line climbs with a ruling grade of 2½%, compensated with grand and bold developments, costly rockwork and tunnels and bridges and viaducts, one after the other. To prosecute this work in the midst of the mountains and with a tunnel of 1 km. long will be very difficult, and the average cost is estimated at $50 000 per kilometer ($80 000 per mile).

The third section, from Ocote to San José del Conde, is 55 km. long. The line follows the ground, and there are not many difficulties; the grades are from 1 to 1½%, following the valley of the River Ahualaltan into which it descends after leaving Ocote, passing through Yxtlan, Ahuacatlan and Tetitlan, leaving the valley by ascending the steps of San José del Conde, where it reunites with the Rio Aveca line just described. The average cost per kilometer is $25 000 ($40 000 per mile).

Engineer Don Resendo V. Corona, by order of the State government, made a study to avoid if possible the principal difficulties which the former lines present. The examination by Señor Corona only indicated a proposed line without estimates of cost. This line left Etzatlan following through the ranchos of Palo Verde, Tlacuache, La Canteria, Puebla de Aconahua, Hacienda of San Rafael, Los Hornitos, La Palma and Los Alamos; then it continues as far as Amatlan de Canas, following a well-known footpath to Palma, then skirting south to the inn at La Silleta, and descending to Amatlan by way of La Canada. This trajectory was 60 km. long with acceptable grades, good opportunities for borrow, an easy development and economical construction.

Besides the principal work which already has been given, this line would require a bridge over the Arroyo of Terbabuena and a tunnel 500 m. long beyond the rancho of Los Alamos.

From Amatlan the line continues to follow the course of the river of that name as far as the point known as Las Juntas; from here it ascends to the pueblo of Garabatoz, passing an extensive "llamora," and below by way of San Valentin to the Hacienda of Tepuchuacan on the north side.

Hence it follows along the right bank of the River Ameca and

passing the confluence with the Ahuacatlan, to San José del Conde, where Señor Corona's examination terminated.

From San José del Conde to Tepic the road is smooth, with light grades passing through Compostelo and the cañon of Miravalles, from which it enters with ease the village of Tepic, the length of this portion being 64 km. and the maximum grade does not exceed 1½%, broken by long stretches of light grade. There is one stretch of 12 km. in the Miravalles cañon, where several bridges and much rockwork are necessary.

The average cost per kilometer is $22 000 ($35 400 per mile).

From Tepic to San Blas there is only one location and a very excellent one, notwithstanding that it is extremely undulating, with a great difference in level from one point to another; the distance is 81 km. and the ruling grade is 2½% passing through Lamedo, La Tortuna, Barranca, Blanco, and following on down to the coast about 30 km. before reaching San Blas. This line has heavy cuts and fills, some hard rockwork and very frequent bridges. The average cost per kilometer on this stretch is nearly $25 000 ($40 250 per mile).

In order to examine the total cost of this line, the foregoing figures are arranged in tabular form, in which are shown the lengths, gradients, cost per kilometer and total cost.

TABLE No. 1.

ESTIMATE OF COST FOR A PROJECTED RAILROAD FROM GUADALAJARA TO SAN BLAS, VIA THE SIERRA DE PAJARITOS.

DIVISION.	Length. Kilometer.	Cost. Kilometer.	Cost. Total.	Grade. Percent.
Guadalajara to Refugio	45	$22 000	$990 000	½
Refugio to San Marco	53	20 000	1 060 000	1½
San Marco to Ocote	50	50 000	2 500 000	2½
Ocote to San José del Conde	55	25 000	1 375 000	1½
San José del Conde to Tepic	64	22 000	1 408 000	1½
Tepic to San Blas	81	25 000	2 025 000	2½
Total	348	$26 900	$9 358 000	
Miles, average cost	216	43 300		

The estimated total cost of the completed line amounts, then, to $9 358 000, as above, in a length of 348 km. (216 miles), which we may increase to $12 000 000 for right of way, station buildings, superintendence, plans, etc.

In this it is assumed that we might expend as much as $20 000 000 on this line, which will earn 10% of that amount annually, a result which would enable the undertaking to be negotiated with the assurance of great success, especially as it may claim an ample subvention, which the Government holds out to the company for its construction.

Unfortunately, the grantee company owns the railway from Mexico to Paso del Norte, with the branch from Trapuato to Guadalajara, and probably it fears that the establishment of the line we treat of would cause competition by opening up a new route for foreign traffic.

This fear the writer believes to be unfounded, because the domestic business is evidently sufficient to sustain the new railroad and earn a profitable revenue; while as to the foreign traffic, notwithstanding that it would take the shorter line, the increased volume of business would make up for the shorter haul. This obstacle, more apparent than real, which the Central Company creates for this line, does not apply to the Chamela line, because it is clear that no line can be established in competition that can obtain larger revenues.

No detailed description of this line is given, for the reason that the complete studies have only been made in part. The résumé which follows will, however, be sufficient.

TABLE No. 2.

ESTIMATE FOR THE PROJECTED RAILROAD FROM GUADALAJARA TO THE PORT OF CHAMELA.

SECTION.	Length. Kilometers.	Cost. Kilometers.	Cost. Total.	Grade. Percent.
GUADALAJARA.				
Cerro de Gachupines	7	$12 000	$84 000	0.75
Avenal	15	12 000	180 000	.50
Santa Cruz	6	25 000	150 000	2.00
Presa del Hurtado	20	12 000	240 000	.50
Tizapan	6	30 000	180 000	2.50
Cacalute	4	12 000	48 000	.25
Canada	6	20 000	120 000	1.50
San Martin de la Cal	30	12 000	360 000	.50
Sta. Maria de las Huertas	10	30 000	300 000	2.00
Arroyo Hondo	6	30 000	180 000	2.00
Quila	25	30 000	750 000	3.00
Toya	30	30 000	900 000	3.00
Tenamaztlan	20	20 000	400 000	.50
Portezuela	8	15 000	120 000	.50
Union de Tula	30	15 000	450 000	.50
Ayugula	10	30 000	300 000	2.00
Autlan	20	15 000	300 000	.50
Obispo	20	30 000	600 000	3.00
Purificacion	70	30 000	2 100 000	3.00
Chamela	90	30 000	2 700 000	2.00
Total	433	$24 200	$10 462 000	
Miles, average cost	269	38 900		

By this résumé it is seen that the 433 km. (269 miles) of this line will cost approximately $10 462 000; and if we add for right of way, stations, etc., as we did in the case of the San Blas line, we obtain a total cost of $13 000 000, on which capital 16% can be earned at the present moment, and probably in time this can be doubled.

In consequence, a company has been organized to undertake this work after verifying the estimates previously prepared, which the writer believes are very nearly correct, having been obtained from local sources and in part based upon the study.

Respecting the line from Guadalajara to Manzanillo, it will probably follow the same line as before as far as Tizapan, from which point it will continue on through the following towns:

	Distances. Kilometers.	Grades.
Hacoalca	36	level
Sayula	56	"
La Cuesta	12	2%
Hapotlan	20	1%
Hapoiltic	20	½%
Tuzpan	30	1%
Tonila	40	2%
Colima	40	1%

The writer does not know the studies which have been made respectively for the company; but he does not believe they will vary much in distances and grades from those above indicated.

From Colima to Manzanillo a railroad has already been constructed and is in operation to Cayutlan, Armeria, Guaracho and Coquimatlan. Its length is 95 km., and consequently the total length of this line will very probably be 403 km. (250 miles).

Respecting its cost, it apparently will not differ greatly from the lines previously studied, inasmuch as the topographical difficulties are distributed about equally. Consequently, we may estimate for standard gauge a cost of $30 000 per kilometer ($48 300 per mile), and of $20 000 for the narrow gauge, which is what has been adopted. With this data the resulting cost of this line will be nearly $8 000 000, and so will need a traffic of 200 000 tons and an equal number of passengers, from which the company which has undertaken the enterprise expects brilliant results.

The writer has gone to the bottom of all the previous considera tions for determining the traffic from the present business between the points from end to end, but it is probable that what was obtained in the early days of the exploration will be doubled by the development of the great natural resources which are contained in the regions to be traversed by the lines which have been considered.

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DISTINCTIVE FEATURES AND ADVANTAGES OF AMERICAN LOCOMOTIVE PRACTICE.

By DAVID L. BARNES, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The locomotives of the United States are not so different from those of foreign countries as might be supposed from the outward appearance; most of the differences are in details, and result from differences in operation, which demand in the United States a large increase in the general dimensions. In studying distinctive features of locomotives of all countries, it is necessary to know in minute detail the conditions of operation under which each class of locomotives is worked, as it is generally found that engines everywhere are well adapted for the work they do. The main difference between locomotives used here and in other countries is a necessary result of the difference in environment. In other countries, generally speaking, the distances are short, competition small, wages low, and money

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893

rentals moderate; in some a governmental control removes all competition. In the United States, long train runs, high wages, sharp competition and high rates of interest define the method of railroad operation so clearly that it is practically beyond the power of any individual company to vary much from the almost universal practice of running heavy trains. It is this necessary policy of heavy train loads that gives rise to the wide difference which is found in maximum hauling power of the American and foreign locomotive. This increased power demands more weight for adhesion and greater steaming capacity; therefore, one finds the American engines heavier and the boilers larger for similar classes of work. This is shown by Tables A1, A2, A3, which give the comparative dimensions of locomotives of various countries.

Many of us in the United States have thought that certain details that are universal here, such as the equalization of the weight between driving wheels, the four-wheeled swiveling and lateral motion truck, outside cylinders, the fire-brick arch and iron tubes, etc., are not commonly used in other countries, and formerly they were not; but now equalizers are common in England, they are standard in Germany, common in France and in other European countries. Outside cylinders are quite universally used in Germany, are common in England, and frequently used in France, Italy and other countries. Fire-brick arches, iron and steel tubes, and lateral motion swiveling trucks are quite common, although not the rule everywhere; so that in looking for such general features of design of locomotive details as are peculiar to the United States, one finds at the present time but little beside steel fireboxes, bar-frames, cast-iron wheel centers and tenders with swiveling trucks. There are many peculiarities in minor details, but these do not affect in any material way the economical operation of the engines.

The use of cabs is dependent, not upon the country, but upon the climate, and they are generally found where the winters are severe. As a rule, all differences in the designs of details can be traced directly to the relative prices of labor. Where labor is high, designs are simple; duplication and interchangeability overrule minor features of durability and efficiency, and in general cast pieces are used instead of wrought. For instance, in the United States the duplication of parts receives more attention than in foreign countries, and it is common to

use a clumsy, heavy, cast-iron piston, that requires less hand labor than the foreign type of piston (the Swedish), which is one of forged steel, very light and strong. Also driving-wheel centers are here made of hard cast iron, while in Europe they are almost universally made of wrought iron.

We are all more interested in such features of locomotive construction as affect the operation than we are in the parts which affect the cost of repairs, for the reason that the other costs of locomotive service are the major part of the total and greatly exceed the repairs. Again, the cost of repairs is so dependent upon the facilities and the price of labor that it is impossible to learn much about the relative merits of designs from a study of the cost of repairs in different countries. Facility for making repairs is the all-important factor of repair costs. Take, for instance, the renewal of driving tires. In this country it was formerly the custom to take an engine into the shop for repairs whenever the driving tires needed turning; in this way the repairs of locomotives were largely dependent upon the durability of the tires. Now, this has entirely changed, and in the most advanced shops general repairs are made only when they are needed. A locomotive may come into the shop in the morning with bad tires and axles and be sent out again at noon with a new set of wheels complete or a new set of tires put on ready for use. The improvements in handling heavy parts and in other facilities for making repairs has materially reduced the cost of keeping up locomotives, so that it is impossible to say what are the advantages of those details of construction which are more common in the United States, without knowing the comparative facilities for making repairs; and furthermore, the difference in the condition on different roads in any one country, in the United States for instance, is great enough to give entirely different results in the cost of locomotive repairs per mile run.

Lack of accurate information has led to considerable discussion within the past two years about the mileage of locomotives before being sent for "general repairs"; but there is no accuracy in comparisons in matters of this kind between locomotives used in different countries, as the conditions are so different. It is not to be expected that a locomotive hauling heavy trains can run so long without a general overhauling as with comparatively light trains. However, it is not the weight of train that governs the mileage made before "general

repairs." The term "general repairs" is indefinite, and some roads keep up the majority of the so-called "general repairs" without taking the locomotives into the shop, while on the other roads some of the "running repairs" are classed as "general repairs," owing to the lack of facilities which compels the locomotive to be considerably dismantled before the parts needing repairs can be made accessible. Therefore, in considering the comparative features of locomotive practice of different countries, the writer has adhered closely to the general features of construction, omitting the minor parts, about which it is impossible to reach a conclusion without knowing in minute detail the conditions and facilities in each particular case; also, such special types of engines as are used in suburban service and for heavy grades are omitted, as they are not common enough to entitle them to be classed as regular practice.

It is not within the scope of this paper to say much about different methods of operating locomotives, but operation so controls designs that one must be understood if the reasons for the other are to be comprehended. The dispute about the economy of running heavy trains has arisen almost solely on account of a lack of definite information on the subject. One may safely grant that if there was any defect in the policy of heavy loads, the exceedingly sharp competition in the United States would have long ago developed the defects, and we should now find some of our roads hauling light trains at frequent intervals. To the contrary, the practice of heavy train loads is universal here. An examination of the cost of freight train expenses in this country, as given by Fig. 1, will show how great is the gain by increasing the train loads when the price of fuel is moderate. The average weight of a foreign freight train, exclusive of engine and tender, is approximately 450 tons. Trains are much heavier on the continent of Europe than in Great Britain. The average weight of an American freight train for level roads is not far from 1 350 tons. Table B gives the data on which Fig. 1 is based. In this table the coal used per ton-mile of total train is taken as a constant for all weights of train. This is only approximately correct, but it is quite near enough for the comparison now being made, as the coal per ton-mile of total train does not vary much with different train loads when the power of the locomotives is in proportion to the train.

The coal per ton-mile of total train is taken as .1275 lb. This corresponds with good practice in the United States. The wages of train crews in this country, on any one road, are nearly the same for all trains.

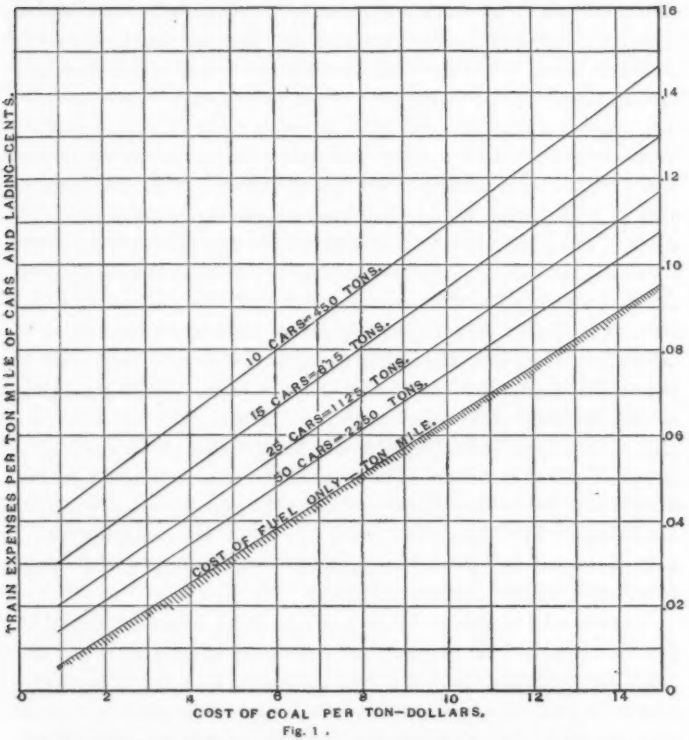

Fig. 1.

Diagram showing the decrease of train expenses per ton-mile of cars and lading accompanying an increase in the weight of trains and with varying prices for coal.

TABLE B.

Number of cars.	Weight of cars. Tons.	Weight of locomotive and tender. Tons.	Engine crew wages per mile run. Cents.	Train crew, wages per mile run. Cents.	Coal used per ton mile of total train. Pounds.	Oil, waste and repairs for locomotives per mile run. Cents.
10	450	70	5.33	7.25	.1275	3.62
15	675	75	5.33	7.25	.1275	3.62
25	1 125	85	5.33	7.25	.1275	3.62
50	2 250	95	5.33	9.25	.1275	3.62

The cost per useful ton-mile for train wages is, in general, the controlling element here, and it decreases as the train loads are increased. In the fuel account there is a saving from heavy train loads up to the point where the engine is excessively overloaded. This is frequently observed from tests of locomotives, but no account is taken of it in the diagram. Take two locomotives and give one a heavy and another a light train; the one with a heavy train will use more coal per mile, but there is a greater useful load in proportion to the dead load of locomotive and tender, and the resultant coal per useful ton-mile is less with the heavy train than with the light train. This reduction in cost of transporting useful loads goes on, even after the load is increased, to a point where the scientific steam engineer would deem the locomotive to be too much overloaded for the economical use of steam. So much bearing does the environment of condition and cost of wages have on the policy of locomotive operation, that in the extreme cases where fuel is less than $1 per ton, the most economical train load is the maximum load that can be hauled by one engine almost regardless of the economy with which the steam is used; this is shown by Fig. 1. So, then, in the United States, heavy trains, high wages, sharp competition and high rates of interest, fix the main distinctive feature of American locomotive practice, which is the greater hauling power of the locomotives. This greater power is obtained in two ways; first, by using locomotives of greater weight, and second, by forcing the boilers to a degree almost unknown elsewhere.

Outside of the greater hauling power, which necessarily requires greater weight and larger parts, and the forcing of the boilers and the machinery, which increases the wear and tear, there is not as much difference in locomotive practice here and in other countries as is generally supposed. From the external appearance of locomotives of different countries, one is led to expect important differences in the vital parts of construction; thus the smoothly encased European locomotive, with a weather shield instead of a cab, often appears to be quite a different machine from the American locomotive with its structural parts exposed to view and with a small house on top of the boiler; yet the organic differences are really small. Each has a pair of single-expansion steam cylinders, either inside or outside of the frames, to which the steam is admitted, and from it allowed to escape by a single plain slide valve actuated by a link motion and eccentrics. The boilers

are both internally fired and have approximately the same arrangement of tubes and parts. The frame construction in both consists of two horizontal and longitudinal beams, made either of bars or plates. The guiding and carrying trucks are perhaps more generally used in the United States, but not to an extent that would justify the claim that a swiveling truck is a distinctive feature of American locomotive practice. Carrying trucks have sometimes two wheels, and again four wheels. Sometimes they swivel, and in addition swing laterally. Where they do not swivel or swing laterally, considerable end play is allowed in the bearings, which gives them, to a considerable extent, the equivalent of a lateral motion. Many engines in the United States are without lateral motion in the trucks, and in Europe one finds many trucks that both swivel and move laterally.

The drivers and connecting rods of locomotives of all countries are alike in all functions; and so on, throughout the principal details, there is but little in the general purposes of construction that can be considered distinctive differences, or differences that should materially affect the economy of operation under the same and equal conditions. However, few as are the important differences in general features, yet there are many and great differences in detail when viewed from the standpoint of the experienced locomotive builder. These differences do not affect the economy of operation, but govern somewhat the durability and affect mainly the amount of labor required in construction, and thereby influence the first cost. The main distinctive features are as follows:

Boilers.—Both in Europe and in the United States, one finds the straight top, the wagon top and the Belpaire boiler. It is impossible to say which of these three types is most used in the United States at the present time; but it appears from observation of the engines built in all countries during the past two years, that there is a prevailing tendency toward a straight top boiler, with a Belpaire or radial screw stay firebox. The crown bar boiler is falling into disuse, owing to its greater weight for equal power and the trouble which it gives when the feed water contains scale-producing compounds.

The difference between the Belpaire and the radial stay boiler lies in the shape of the top of the firebox; it is rectangular for the Belpaire and semi-circular for the radial stay type, as shown in Figs. 2 and 3. The crown bar boiler is shown in Fig. 4.

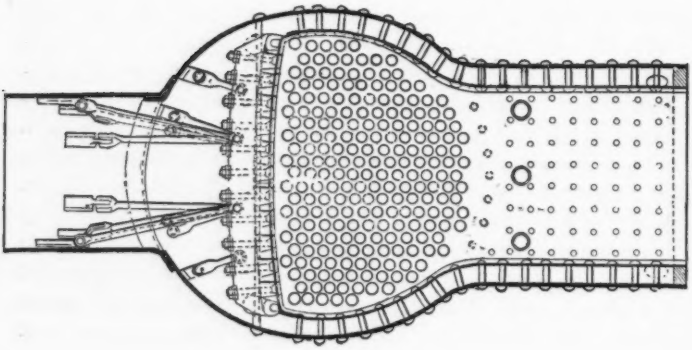

Fig. 4.
American Crown-Bar Firebox.

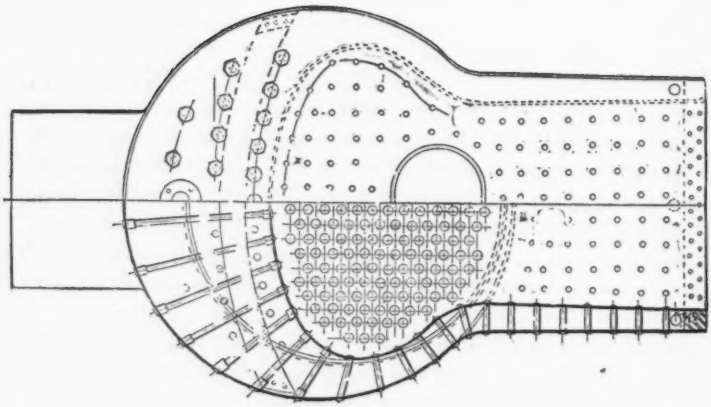

Fig. 3.
American Radial Stay Firebox.

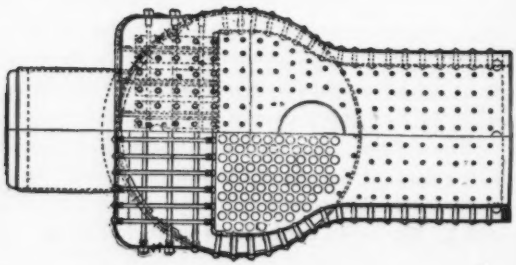

Fig. 2.
American Belpaire Firebox.

In some sections of the United States there are large amounts of fine coal and slack that cannot be burned in the ordinary locomotive; and in such places here, as in Belgium, one finds a peculiar construc-

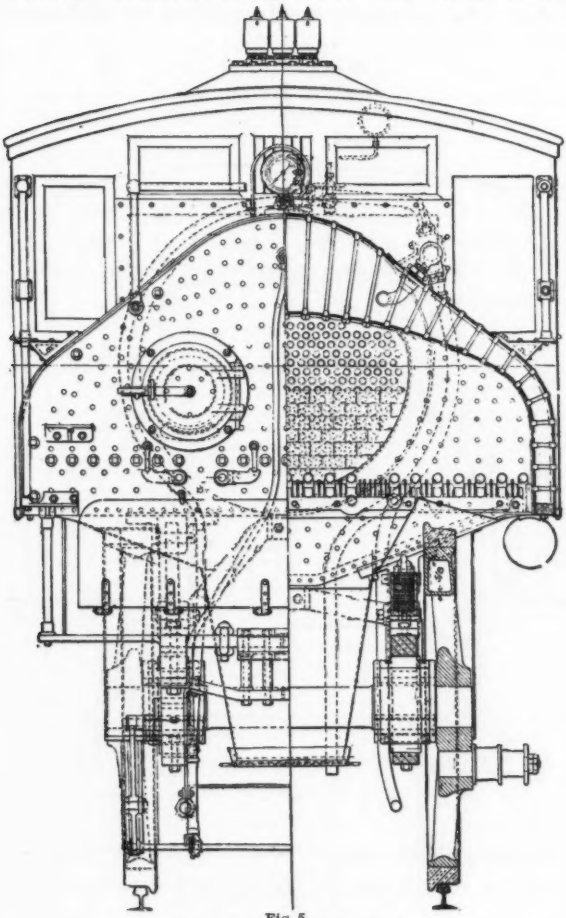

Fig. 5.
American Wootten Radial Stay Firebox.

tion of locomotive fire-boxes. In this country the most common type for fine coal is the Wootten. The form generally used is that shown in Fig. 5. A new form, having a Belpaire top, has been proposed.

It is not unlike that used in Belgium, and shown in Fig. 6. The Wootten type of boiler has been very successful where there is a sufficient quantity of fine coal; but on some western roads in the United States, where it has been tried, there has not been enough fuel to keep

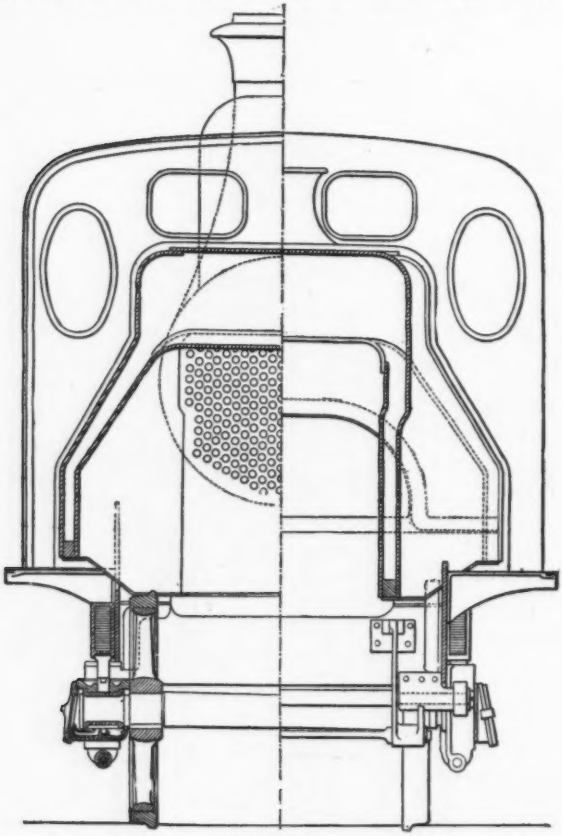

Fig. 6.
Belgium Belpaire Firebox.

the engines supplied. Add this to the disadvantage of having to keep in stock two classes of fuel for engines at the same terminal, and the difficulties experienced with the large crown sheets, and the reasons are found for the infrequency of this type of firebox in sections of

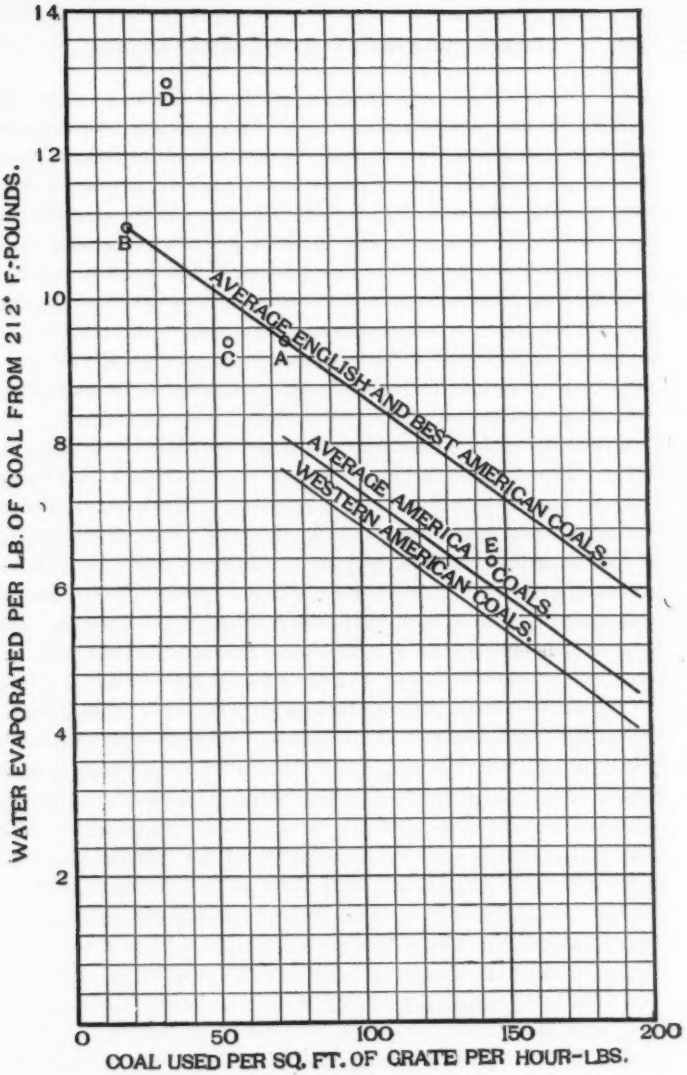

Fig 7.

Diagram showing the decrease in evaporation of water per pound of coal from and at 212° Fahr. which follows an increase in the coal burned per square foot of grate per hour, with English and American coals.

NOTE.—A to B = English practice.
C = English coal as determined by Rankin.
D = English coal as determined by Kennedy and Donkin shop tests of a locomotive.
E = American coal—Brazil block—Indiana—Goss, at Purdue University shop tests.

the United States remote from an abundant coal supply. Locomotive boilers with grate areas as large as these do not use good coal economically, as the limit of economical increase of grate area for free-burning fuel is exceeded. As seen from Fig. 7, an increase in grate area, which is, of course, followed by a decrease in the rate of combustion of coal per square foot of grate per hour, is conducive to economy; but there is a limit to this increase, which cannot be exceeded without loss from incomplete combustion and excess of air supply through the grates. Large grates are difficult to cover properly, and if the fuel is free-burning it is impossible to regulate the fire accurately, and much heat is lost by the blowing of the safety valves when the train is at a station or while descending grades.

There is nothing, therefore, in the general shape and design of boilers in locomotives that can be said to be distinctively American or foreign; but when we look into the materials of construction, we find the American locomotive boiler differs materially from all others, and it may be said that the use of steel for fireboxes is distinctively an American practice. In Great Britain, where all portable engine boilers and marine boilers are built with steel fireboxes, there is not one railroad company using steel for locomotive fireboxes, and there are but a few steel locomotive fireboxes in the whole of Europe.

The tubes of foreign locomotives are more generally made of brass, and in the United States of iron and steel. From an American standpoint, copper fireboxes and brass tubes have no advantages that would induce the railroads here to use them. Good steel fireboxes do not crack, and good iron tubes last so long that the cost of depreciation and repairs depends more upon the purity of the feed water and the care which the boilers get in washing out than upon the material of the fireboxes and tubes; and no one here believes, so far as the writer knows, that brass tubes or copper fireboxes would have a longer life or cost less in the end than good steel boxes and the best iron tubes. It is true, of course, that copper sheets and brass tubes, even at a high price, are cheaper in the long run than bad steel sheets and inferior iron tubes at prices next to nothing; but careful railroad companies do not use bad material for firebox sheets and tubes. The best steel fireboxes last in service from 12 to 15 years. The average life is much less, and is about the same as that of the copper fireboxes used in Europe, which, according to the repair statements of some foreign railroads, is from 8

to 10 years. The cost of repairs resulting from broken stay bolts, burned sheets, and cracks due to scale deposits and vibrations, which are common to all locomotive boilers using bad water, regardless of the material of the fireboxes and tubes, is so great that the replacement of steel firebox sheets that are worn out by normal service is not such a comparatively expensive repair as might be supposed. The scrap value of a steel firebox is small; in fact, may be considered *nil;* but it is purchased for about 4 cents a pound, while copper sheets cost from 20 to 30 cents a pound. The scrap value of copper is uncertain, and depends upon the market. Ten cents a pound is not too high an estimate for the loss per pound of copper between the first cost and the scrap. This difference will permit the steel firebox to be renewed at least twice, and a closer estimate shows that in this country, with the prevailing prices, two steel fireboxes can be put into a locomotive boiler for a cost, including labor, that will not exceed the net cost of a copper firebox with an allowance for scrap. Each renewal of a cracked copper sheet costs much more than the renewal of a steel one, and cracks are to be expected with bad feed water and careless boiler washing, no matter what the material. Even if the copper was more durable than the steel firebox, the fact remains that the American locomotive has practically passed its period of usefulness after about 10 years of service on the prevailing American plan of running heavy trains and pooling engines. This, taken together with the continual development in size and construction of engines in general, tends to so lessen the period of years during which a locomotive is used in this country, as to make it neither advisable nor desirable to put into construction high-priced material, or complicated parts requiring much hand labor, to get a longer life of any part than the life of the engine as a whole. Steel of a proper kind is as good for locomotive boilers as for marine boilers, and those who formerly used copper for marine fireboxes have long since abandoned it for steel, this material having been found to be the more satisfactory.

It has been claimed that an advantage accrues to a railroad company using copper and brass for heating surfaces on account of the greater conductivity of those materials; but this apparent advantage is reduced by the loss due to the greater thickness of the copper sheet; and considering the probability that iron and steel will convey heat from the fire to the water faster than the water can absorb the heat,

there is little, if any, actual advantage in conductivity left for the brass and copper heating surfaces. A very little scale will remove entirely any advantage there might be found otherwise in the greater conductivity of brass and copper. Americans are not without experience with copper and brass in locomotive boilers, and it may be accepted that the continued successful use of steel fireboxes and iron tubes in this country is a distinctive feature of American locomotive construction, and one that actual service has shown to be economical under American conditions of railroad operation; and there is much reason to believe that these materials would be quite as economical in any other country, especially as nowhere else are the fires in locomotive boilers forced as much as they are here. The continued use of copper fireboxes in foreign locomotives, after so much marine experience with steel, is a surprise to American railroad men.

Otherwise than the firebox material and the differences in general dimensions given in Tables A1, A2, A3, there are no important distinctive features of American locomotive boiler construction.

Fig. 8.
American Bar-Frame.

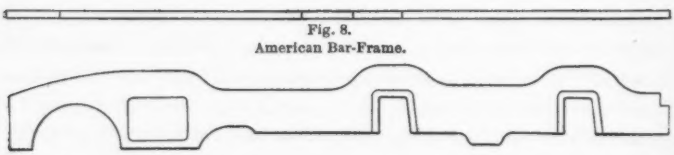

Fig. 9.
Foreign Plate-Frames.

Frames.—The American locomotive frame is universally of the bar type, while that of the foreign is generally of the plate type. These types are shown in Figs. 8 and 9. It may be said that the bar construction is an American plan, as it was first generally adopted here, and it is a popular idea that it was designed to give locomotives ver-

tical flexibility on rough track; but for this it was unnecessary after the adoption of equalizing levers to connect the points of support and to allow the individual carrying-wheels to rise and fall without causing excessive changes in the weight thereon. In fact, the bar-frame has been so securely attached to the rigid and stiff boiler shell that its vertical flexibility, so apparent when the bar-frame lies in the frame shop before erection, disappears almost entirely when it is placed on the engine and secured to the boiler. American builders of locomotives have been criticised for the construction of a bar-frame, on the ground that such a frame is stiffer than a plate-frame laterally, and therefore not so well adapted to the perhaps more crooked roads of this country; but there is no just ground for such a criticism, as the difference in the stiffness of the bar and plate-frame is apparent and not real. As these frames lie on a machine-shop floor, the plate-frame is the more flexible laterally; but if both are placed in position and braced, as they always are, there is no practical difference in the stiffness of them. Both form part of a deep horizontal girder, having heavy chords, the girder as a whole being attached to a stiff and rigid boiler. It is practically true that neither the plate nor the bar-frame has a superior lateral or vertical flexibility which results in any beneficial effect on the action of engines in service. However, some engines have been built in this country without much lateral bracing, and with the boiler barrels so high as to render the attachments to the frame thereto more flexible, and these engines have therefore more flexible frames than is the general practice; but, so far as can be seen, the results from service are not different from other engines having comparatively stiffer frames.

The bar-frame has the advantage of giving better opportunities for attaching the details of the engines, but the plate-frame being without welds can be made with more security from breakage. In this country the bar-frame lends to the engine the accessibility necessary in cold weather, when oil congeals and the motion-work needs constant watching. So, too, it facilitates the examination of the machinery in the short intervals of stopping during long runs. Probably this advantage will continue in the future, as it has in the past, to promote the use of the bar-frame in this country, where the extremes of weather and the rough handling of engines require all parts to be accessible and within the range of the engineer's and fireman's eyes as they look

about the machinery during the short stops on long runs. In some other countries it has been found practicable to oil the main bearings of the engines from pipes leading from the cab (a manifest advantage with the deep plate-frame which obstructs the oiling); but here the extremely cold weather makes such a plan impracticable.

Recently, to avoid breakages of welded bar-frames, some American builders have made them from rolled steel slabs, the slabs being rolled from 3¼ to 4½ ins. thick, and then planed on both sides and cut out on slotters to the shape and form of the welded frames. The objection to this is the increased cost and the difficulty of welding the steel if it is broken in service. On the other hand, improvements are being made in the welded iron frames by using muck bar instead of scrap-iron for the shapes. Scrap in this country now contains such a large and unknown percentage of steel that it is no longer safe to use it for parts that give much trouble from breakage.

It is not to be understood from what has been said here that slab frames do not break, for they certainly do; but not as frequently as the bar-frames; yet the cast horn-blocks used on slab frames often break, so that altogether there may be after all no advantage with a slab-frame in point of freedom from breakage.

Equalization.—The equalization of weight between wheels, so universal here, and so frequently considered by us as being used but little on foreign engines, is not a distinctive feature of American construction. It is almost universal in Germany, and is frequently used in Great Britain, France and elsewhere. The plan of equalization is in general the same everywhere; it provides three points of support for the body of the engine, so that whatever be the position of the wheels vertically within about a 2½-in. limit, the weight on the wheels will not be materially different. Without equalization on a rough track it is possible to have an excessive weight on one pair of wheels. Generally the leading truck, or the leading pair of drivers when there is no truck, is taken as one of the points of support. The other two points of support are the resultants of the two equalizer systems, one on each side of the engine. Figs. 10, 11, 12, 13 and 14 show the more common methods adopted for equalization in this country.

When equalizers are not used, the weight distribution depends upon the adjustment of the spring hangers. When there is a pair of carrying wheels front and back of the drivers, as on some classes of

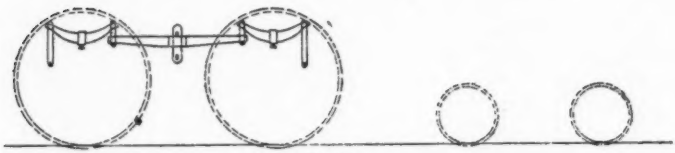

Fig. 10.
Equalizing system for American Eight-Wheel Locomotive.

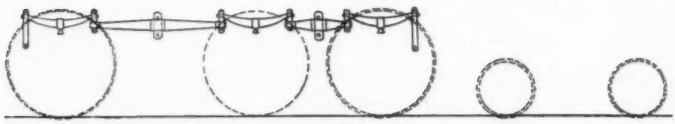

Fig. 11.
Equalizing system for American 10-Wheel Locomotive.

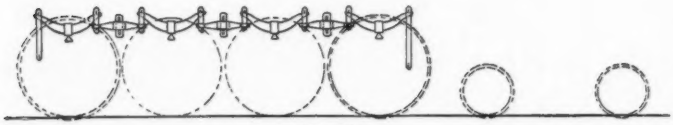

Fig. 12.
Equalizing system for American 12-Wheel Locomotive.

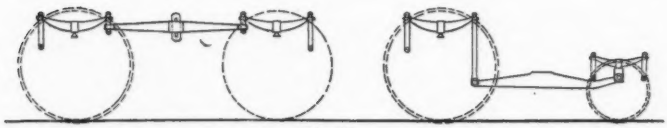

Fig. 13.
Equalizing system for American Mogul Locomotives.

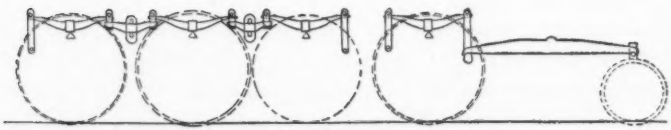

Fig. 14.
Equalizing system for American Consolidation Locomotives.

foreign locomotives, the weight on drivers can be changed greatly by changing the lengths of the spring hangers. The variation in weight on drivers that can in this way be produced is as much as 50 per cent. Of course, such changes can only be made by changing the weight on the trucks. If the springs are stiff, an equalization system is abso-

lutely necessary in this country, with its large percentage of uneven track, in order to prevent the hard riding of the engines and the breakage of springs ; but with long and flexible springs, there is less need for equalization. This appears from the analysis of the changes of weight on drivers accompanying various deflections of the track when the engines have stiff or flexible springs, as shown by Fig. 15.

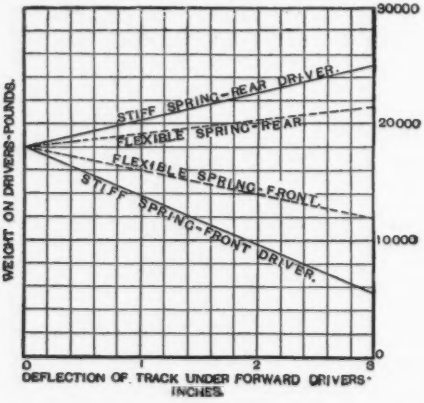

Fig. 15.

Diagram showing the change in weight on drivers of a four-coupled American eight-wheel locomotive produced by a deflection of the track when equalizers are not used between the coupled wheels.

Normal load on track per wheel = 18 000 lbs.
Stiff spring deflects 2 ins. with 13 000 lbs.
Flexible spring deflects 4 ins. with 13 000 lbs.

It will be seen from this diagram that a decided and abrupt change in the vertical alignment of the track produces much change in the distribution of weight on drivers when there are no equalizers, even when very flexible springs are used; and therefore in this country, where rail joints are liable to be low, the only way to keep an approximately uniform weight on drivers at slow speeds is to provide for equalization. It is impossible in this paper to enter upon a discussion of the common roughness of track in this country; yet it is best to say that the main track of the well-supervised roads here is quite sufficiently well kept up to permit engines to run without equalizers; but the sidings and the average track are in such condition as to demand an equalizing system to give durability to the springs and to prevent severe twisting strains on the axles and the breakage of crank pins by sudden changes of load.

It is a grave question whether the use of equalizers between the driving wheels of locomotives is best for the track joints; for example, if the locomotive with the weights assumed for Fig. 15, has equalizers and is run over a weak and low joint, that joint will be subjected to the full pressure on each driver, or 18 000 lbs.; but if the drivers are not equalized, the pressure on the joints depends

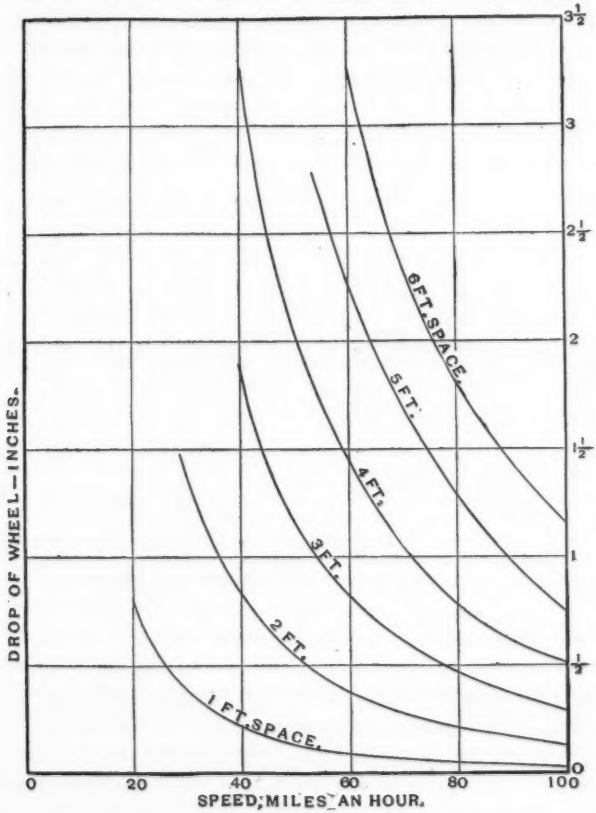

Fig. 16.

Diagram showing the distance that a locomotive driving wheel will drop or move downward by the action of gravity and the force of the spring above the wheel while passing over various spaces in the track at different speeds.

upon the deflection of the joints. If, with stiff springs over the wheels, the joints deflect as much as 1½ ins., the load thereon would

be but 11 750 lbs. However, the foregoing is true only when the engine is moving slowly, and therefore only applies to the bad track common on sidings and in yards.

At speed the inertia of the driving wheels and their attachments resists any sudden downward movement of the wheel into a depression of the track. At 80 miles an hour, the time of passing the 2 ft. preceding a rail joint is about .017 second. The force of gravity and the force of the spring above the driver would cause the driver to move downward but about .206 in. in this interval (see Fig. 16), so that even if the statical load of the driver under normal conditions would cause 1 in. deflection of a joint, yet, owing to the inertia of the driver and its attached parts, the force of the spring above the wheel

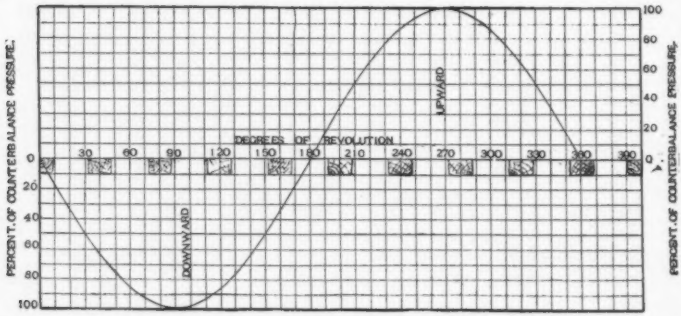

Fig. 17.

Diagram showing the percentage of the maximum counterbalance pressure on the track which is exerted at different points during a complete revolution of a locomotive driving wheel when the track is rigid and does not deflect under the load due to the counterbalance pressure.

and the action of gravity would only move the driver downward .206 in. Thus, while an equalizing system between driving wheels has the tendency to keep the weight on drivers uniform, and also throws a full load on a weak joint at low speeds, yet at high speeds the load is materially reduced by the inertia of the wheel and its parts, and the pressure of the wheels on the rail is by no means uniform, although the equalizers be provided. Also, at high speeds the variation in weight on the track produced by the counterbalance quite disarranges any distribution of weight that would otherwise come from an equalizing system. Figs. 17, 18 and 19 show that so far as the pressure of the wheels on the track at high speeds is concerned, much more depends

upon the rigidity of the track and the amount of counterbalance than upon the equalizing system.

Counterbalancing.—American locomotives ride easier than the foreign on account of the longer springs, the higher boilers, and the greater total weight. The counterbalancing, fore and aft, is quite perfect here, but more counterbalance is used; not more in proportion to the amount of the weight to be balanced, but more in total; the reason being that much less attention has been paid to the reduction of the weight of the reciprocating parts in the United States than in other

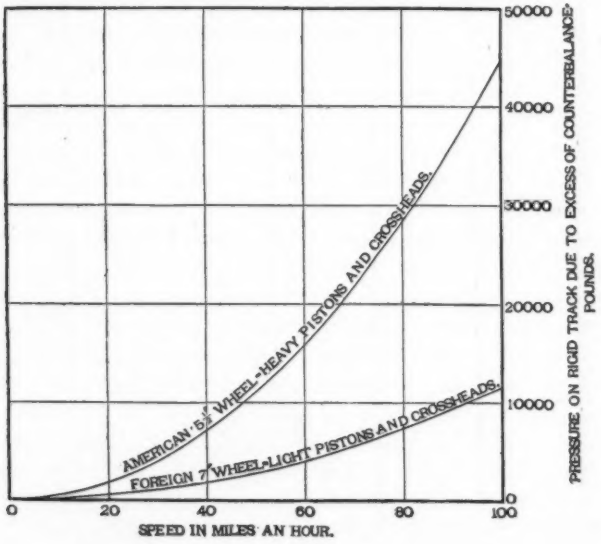

Fig. 18.

Diagram showing the maximum pressure on a rigid track due to that portion of the counterbalance of a locomotive that is used to counteract the horizontal effect of the reciprocating parts of American and foreign locomotives of the same size of cylinder. This diagram also illustrates the reduction of the variation of pressure of a driving wheels upon the track that follows an increase in the diameter of the driving wheels and a reduction of the weight of the reciprocating parts.

countries. Perhaps the reason is, that to reduce the weight of reciprocating parts beyond a certain limit entails a decided increase of cost; but whatever be the reason, one finds the weights of the pistons, crossheads, piston rods and connecting rods, heavier on engines in this country than in Europe. A fair estimate of the proportion of the

weights of these parts, as used here and in foreign countries, is as follows:

Foreign	1.
American	2.38

Recently more attention has been paid to the reduction of the weights of reciprocating parts of locomotives in the United States, and

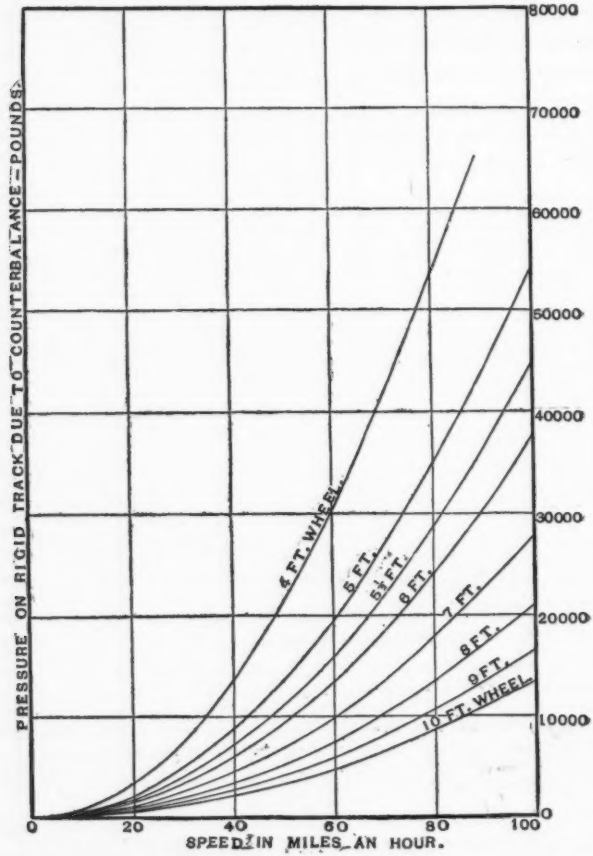

Fig. 19.

Diagram showing the decrease in the maximum track pressure, of that part of the locomotive counterbalance that is used to counteract the horizontal effect of the reciprocating parts, which accompanies an increase in the diameter of the driving wheels on the same engine with the same reciprocating parts, 18 x 24 in. cylinder.

a few of the latest designs have 25% less reciprocating weight to be balanced than is found in average American practice.

If there should be allotted to counterbalancing of locomotives the importance that is given it by some of our railroad track and bridge experts, it would, perhaps, be necessary to class the heavy reciprocating parts used here as a distinctive feature, and a bad one, of the construction of American engines. It is not uncommon for our track experts to advocate the removal of that portion of the counterbalance which is put in to counterbalance the reciprocating parts. Recently attention has been so strongly directed to this matter here that a step in advance has been promised, and light cast-steel and wrought-iron pistons are being talked of; but the improvement proposed is small and does not give the light weight of reciprocating parts that is found in other countries.

It is not just to say that all American engines have such very heavy reciprocating parts as has been indicated here; but as a rule American engines have these parts much heavier than is necessary, and this leads to the excessive counterweights, which have given ground for a just criticism of this feature of American locomotive design. For instance, some compound locomotives have been built in this country with a single piston weighing over 800 lbs. The builders did not realize at the time the result of this, and put in as much counterbalance as was necessary to make the engine ride well. The result was almost disastrous to the track at 60 miles an hour, the maximum pressure on the rail reaching nearly 50 000 lbs. per wheel. At this speed the wheels of this engine lifted from the rail when the counterbalance was up and seriously affected the track when the balance was down, as has been the case before both in this and other countries when engines have been overbalanced. In several instances, both here and abroad, short sections of track have been badly damaged by running overbalanced engines at high speed. In one case it was caused by running an engine with small wheels at high speed without the parallel rods.

The comparative effect of counterweights of some American, English, German and French high-speed locomotives is given in Fig. 19. This diagram, when read in connection with Figs. 15, 16, 17 and 18, shows how the distribution of the weight of a locomotive on the track is affected by the counterweight, and by the deflection of the rails when engines are moving at high speed. All

these matters so affect the limit of weight that is admissible on one driving wheel, that those who have to determine the limit for any given track need to make careful analysis of the detail designs of locomotives in order to reach safe conclusions. Such analysis is one of the duties of the railroad civil engineer, and in studying this problem, the long lengths of track over which is spread the downward action of the counterbalance, as shown by Fig. 17, must not be forgotten.

It has been shown that it requires time for a wheel to drop into a depression in the track, and how this materially affects the load on a weak joint, yet this statement needs modification to the extent that it is affected by the distance between the center of revolution and the center of gravity of the driving wheels. This distance is about 1.3 ins. for the wheel considered in the counterbalancing for an American engine, given in Fig. 18. A wheel will follow instantly any deflection of rail up to the amount of the distance of center of gravity from center of figure, and therefore on a track having such elasticity that it would deflect, under the additional load brought upon it by the counterweight, nearly as great a distance as that between the center of gravity of the wheel and its center of figure, there would be but little additional pressure brought on the rail by the centrifugal tendency of the counterbalance, the reason being that the wheel would then revolve nearly on its center of gravity, and would have, therefore, but little centrifugal tendency.

This is an example of the extreme condition, and only serves to illustrate more clearly the point now being made, which is that such deflection of the track as actually takes place on good roadbeds reduces materially the effect of the counterbalances. In this matter some have erred by assuming the whole centrifugal tendency that would exist if the wheel revolved on its center of figure, and the track did not deflect under the increased load. Such deflection of the track as actually does occur has a large modifying effect on the variation of pressure on the rail, caused by the centrifugal tendency of the counter-balance for the reciprocating parts. No doubt the flexible track used here has decreased considerably the damage that would otherwise have resulted from the use of heavy reciprocating parts if our track had been laid on a more rigid roadbed.

Centrifugal action is not, strictly speaking, a force, but is only a

tendency, and does not exist unless the wheel is constrained to revolve on a point outside of its center of gravity. In a large, heavy wheel, if the counterbalance be light, the distance from the center of gravity to the center of revolution is so small that the centrifugal tendency that would exist on a rigid track is greatly reduced on a comparatively flexible track.

Driving-Wheel Centers.—In this country driving-wheel centers are generally made of cast iron, with the tires held on by shrinkage alone. The Pennsylvania Railroad has had a few wrought-iron centers in use for several years ; the Chicago and Erie Railroad has quite a number of wrought-iron centers of the Vauclain type, and there are a few wrought drivers on other roads here; but, in general, a hard cast iron is used. In foreign countries the wrought-iron or cast-steel driving-wheel center is common practice, and tires are held on by retaining rings. The retaining ring, or some other auxiliary tire fastening, is necessary in addition to the security obtained from shrinkage of the tire when a wrought or light cast-steel center is used, owing to the deflection of the light center under the heavy stresses caused by shrinkage of the tire, and it is this which governs the use of retaining rings and other tire fastenings. Such wrought-iron centers as have been used here have had an auxiliary tire fastening, and where light centers are common, tire fastenings are common also. Cast-iron centers for wheels up to 6 ft. in diameter have been proved to be perfectly safe without auxiliary tire fastenings, and such centers are used in this country mainly on account of the low first cost. Wrought centers would do no better service than cast ones in our smaller wheels, and, therefore, it is doubtful if wrought-iron centers will ever be much used in this country for wheels less than 5½ ft. in diameter. One advantage of our heavy driving wheels is the reduction of the distance between the center of revolution and the center of gravity, and this tends to reduce the effect of the heavy reciprocating parts used here.

Tenders.—The foreign tender is generally of the type shown in Fig. 20, and the American of the type shown in Fig. 21. The American differs from the foreign mainly in the frames and trucks. In the American there are two trucks of the swiveling type. Lateral motion trucks are not generally used here for tenders. Taken altogether, the foreign tender appears to be more practical than the American, and the service trial of one with the Webb compound on the Pennsylvania road during

the past two years has led some of our railroad engineers to recommend an extensive trial of six-wheel tenders in the place of the eight-wheel, in order to gain, if possible, the greater simplicity and accessibility and the less weight of the foreign type.

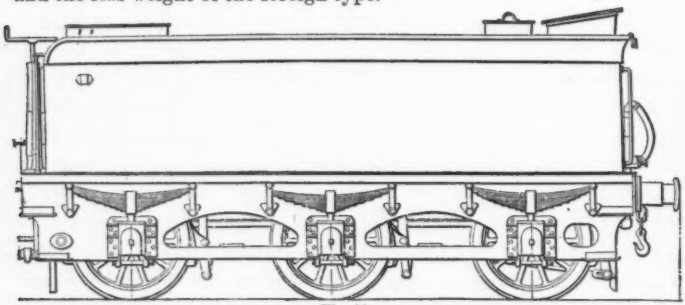

Fig. 20.
Foreign Tender.

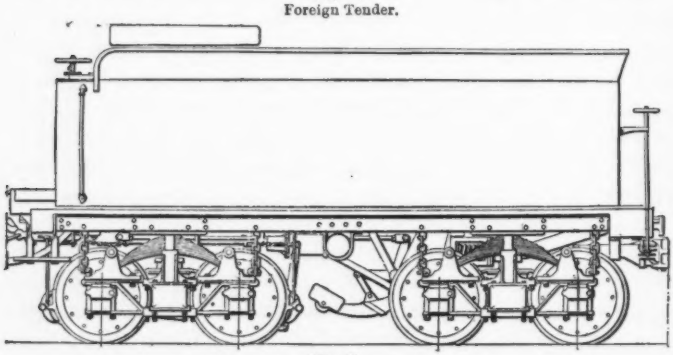

Fig. 21.
American Tender.

Method of Operation.—The forcing of American locomotives, which results from the necessary policy of hauling heavy train loads, is perhaps best illustrated by Fig. 7, which shows the decrease of the evaporation of water per pound of coal in a locomotive boiler which accompanies an increase in the coal "used" per square foot of grate per hour. The term "used" is perhaps better than "burned," because much of the coal that is thrown into a locomotive firebox is not burned, but goes through the tubes in the form of cinder and smoke. This diagram is taken from many results obtained within the last three years on American railroads, during locomotive tests, where

the coal used per square foot of grate per hour has varied from about 60 to nearly 200 lbs. That there is the marked decrease in evaporation accompanying an increase in the rate of coal used that is shown by the diagram is becoming well known here, and has recently led to a stronger conviction about the advantage of using large grate areas. In some recent tests of three locomotives, having different grate areas, it was found that the coal used per square foot of grate varied almost in an inverse proportion to the total area of the grates, and the water evaporated per pound of coal decreased with the increase in coal used almost exactly as shown on the diagram. This led to the conclusion at the time that the larger the grate that could be put on a locomotive the greater would be the evaporation per pound of coal used, provided always that the grate does not exceed in size that which can be properly handled by the firemen. In some cases we have made the grates too large, but as a rule a good fireman can properly fire a furnace with a grate not exceeding 10½ ft. in length, and up to this length it is practicable to go. On roads where a deep firebox with a comparatively small grate has been used for a long time, the firemen object strongly to the introduction of a shallow firebox and a larger grate, as it requires more skill and attention.

On the coal diagram, Fig. 7, there are three lines—one showing the evaporative power of Western American coal, such as is commonly used in the vicinity of Chicago and farther west; the next line gives a fair average of the coal used throughout the United States; the upper line shows the better quality of the best American and the average English coal. Perhaps the difference in the English and American coals is better illustrated by the points representing individual tests by Kennedy and Donkin, and the results obtained by Mr. Webb with the compound locomotive "Greater Britain." These points are considerably above the highest results from American locomotives using the best American coal (see the result obtained by Professor Goss during the Purdue University shop tests of a locomotive). The continuation of the upper line on the diagram from *A* to *B* illustrates the difference in the way in which locomotives are worked here and in foreign countries. It is not common, except in the United States, to use over 70 lbs. of coal per square foot of grate per hour. The difference between the evaporation per pound of coal used from *A* to *B* and that given on the line representing the average American coal, shows how much greater is

TABLE C.

Analysis of Coal Found in Various Parts of the Earth.

Country.	Location.	Commercial Name of Coal.	Fixed Carbon.	Volatile matter including carbon, hydrogen, oxygen, nitrogen, sulphur and other volatile substances except water.*	Ash.	Water.	Remarks.	Sulphur.
United States..	Connellsville, Pa.....	Broad Ford.....	59.616	30.891	8.233	1.26	Pennsylvania coking coals.....	0.784
" ..	" "	Coketon.....	65.72	22.55	11.71	....	" "	0.70
" ..	Irwins "	Pennsylvania gas coal	54.88	39.09	6.98	.....	" " washed slack.....	0.96
" ..	Allegheny Mt. "	Barrington B.....	61.843	29.825	6.93	1.40	" "	2.60
" ..	" "	Lilly's Station E....	70.52	23.709	5.058	0.715	" "	1.459
" ..	Blossburg "	Arnot, Seymour vein	71.574	22.493	4.753	1.18	" " washed slack.....	0 907
" ..	Allegheny River, Pa.	Lower Freeport.....	54.223	37.137	7.34	1.30	" " "	1.312
" ..	Beaver County "	Hulmes & Brother...	54.619	38.901	4.080	2.40	" "	0.791
" ..	New River, W. Va...	Quinnimont.....	75.89	18.49	4.68	0.94	West Virginia " washed slack.....	0.30
" ..	" "	Fire Creek.....	75.02	22.90	1.47	0.61	" "	0.56
" ..	" "	Longdale.....	72.32	21.65	5.27	1.03	" "	0.27
" ..	" "	Nuttallburg.....	69.00	30.37	1.07	0.34	" "	0.78
" ..	Leetonia, Ohio.....	Washingtonville.....	56.04	40.13	1.80	2.56	Ohio "	0.53
" ..	Steubenville, Ohio..	Shaft coal.....	65.90	31.88	1.80	1.40	" "	0.98
" ..	Tracy City, Tenn....	Sewanee.....	61.00	29.30	7.80	1 60	Tennessee "	Trace.
" ..	Whiteside, "	Kelly	74.20	21.80	2.70	1.30	" "	0.70
" ..	Rockwood, "	Roanoke Iron Co....	63.74	26.950	7.82	1.49	" "	0.330
" ..	Warrior Field, Ala...	Pratt seam.....	61.60	32.398	5.416	1.508	Alabama "	0.918
" ..	Cahaba, " ...	Helena.....	59.58	35.03	6.050	....	" "	0.66
" ..	Big Muddy, Ill.....	Mt. Carbon.....	59.13	32.69	1.81	6.37	Illinois "	0.76
" ..	El Moro, Col.....	El Moro.....	55.86	38.23	3.59	1.32	Colorado "	
" ..	Crested Buttes.....	Crested Buttes.....	72.60	23.20	3.10	1.10	"	
" ..	Peru, Ill.....	Illinois.....	51.26	33.90	4.54	10.30	Rudy, 1878.	
" ..	Youghiougheny, Pa.	Youghiougheny.	66.85	28.90	3.35	0.90	Professor Weber.	
" ..	Briar Hill, Ohio.....	Briar Hill.....	62.66	32 58	1.16	3.60		
" ..	La Salle, Ill.....	Illinois.....	43.95	39.40	8.43	8.22	University of Illinois, 1889-1890. Clark.	
" ..	Peru, "	"	47.20	37.19	6.61	9.00	" "	
" ..	Bloomington, Ill....	"	45.20	35.99	14 71	4.10	" "	
" ..	Streator "	"	45 30	38.88	8.60	7.20	" "	3.30
" ..	Oakwood "	"	46.01	37.55	8.65	7.80	" "	
" ..	Fairmount, "	"	47.05	31.80	13.05	8.10	" "	
" ..	Danville, "	"	53.00	32.55	3.65	11.00	" "	
" ..	" "	" ...	45.37	43.70	6.15	5.78	" "	
" ..	" "	"	46.43	37.07	10.88	5.62	" "	
" ..	Lincoln, "	"	44.50	34.99	12.06	8.45	" "	
" ..	" "	"	49.50	31.30	11.70	7.50	" "	

"	"	Mt. Pulaski,	"	"	46.53	35.82	9.97	7.68	"	"	
"	"	Niantic,	"	"	47.40	36 25	8.47	7.88	"	"	
"	"	"	"	"	45.50	34.15	8.50	11.85	"	"	
"	"	Riverton,	"	"	48.45	35.39	9.78	6.38	"	"	
"	"	"	"	"	44.30	38 45	6.15	11.10	"	"	
"	"	Barclay,	"	"	46.25	35.67	10.71	7.37	"	"	
"	"	Pana,	"	"	46.95	36.37	9.46	7 22			
"	"	Assumption,	"	"	50.10	41.20	4.80	3.90	University of Illinois, 1889-1890. Clark.		
"	"	Mt. Olive,	"	"	44.49	35.43	11.11	7.97	"	"	
"	"	"	"	"	51.50	35.00	8.20	5.30	"	"	
"	"	Odin,	"	"	50.86	33.99	9.08	6.07	"	"	
"	"	Odin,	"	"	46.90	41.10	6.10	5.90	"	"	
"	"	Kinmundy,	"	"	47.45	34.00	11.55	7.00	"	"	
"	"	Sandoval,	"	"	50.86	35.07	6.88	7.19	"	"	
"	"	Centralia,	"	"	45.50	38.18	8.04	8.28	"	"	
"	"	Milwaukee, Wis	Braceville,		45.30	40.05	8.95	8.82	Av'ge of 17 analyses. C.M.& St.P.R.R. Gibb's, '92.		3.12
"	"	"	"	Pittsburgh,	53.22	39.59	6.88	1.99	"	"	1.68
"	"	Pittsburgh, Pa	Monongahela, Gas,			35.74	6.66	....	Thurston.		
"	"	Bloomington, Ill	Illinois,		53.12	34.02	4.96	7.90	Rudy, 1878.		
"	"	Briar Bluff,	"	"	48.54	28.96	9.90	12.60	"		
"	"	Barclay,	"	"	44.78	27.32	17.10	10.80	"		
"	"	Carbondale,	"	"	59.84	26.40	7.40	6.36	"		
"	"	Catlin,	"	"	48.42	31.08	12.70	7.80	"		
"	"	Danville,	"	"	31.20	.....	14.64	9.60	"		
"	"	Du Quoin,	"	"	60.60	23.54	7.00	8.86	"		
"	"	Elmwood,	"	"	55.30	27.60	9.50	7.60	"		
"	"	Farmington,	"	"	50.48	29.28	11.72	8.52	"		
"	"	Grape Creek,	"	"	51.32	28.34	10.60	9.74	"		
"	"	Kewanee,	"	"	49.66	27.60	7.14	15.60	"		
"	"	Lincoln,	"	"	46.64	27.60	14.84	10.92	"		
"	"	Lombardville,	"	"	51.74	31.38	7.46	9.42	"		
"	"	Mt. Carbon,	"	"	66.50	24.68	2.70	6.12	"		
"	"	Oglesby, 2d vein,	"	"	49.32	30.84	7.72	12.12	"		
"	"	" 3d "	"	"	55.88	30.34	3.72	10.06	"		
"	"	Du Quoin,	"	"	53.69	32.03	7.44	6 84	University of Illinois, 1889-1890. Clark.		
"	"	"	"	"	54.08	30.35	8.90	6.67	"	"	
"	"	Big Muddy,	"	"	56.00	32.15	4.90	7.85	"	"	
"	"	Carbondale,	"	"	57.50	33.65	4 60	4 25	"	"	
"	"	Youghiougheny, Pa	Youghiougheny,		60.82	33.13	4.65	1.40	"	"	
"	"	"	"	"	58.10	35.80	5.40	0.70	"	"	
"	"	La Fayette, Ind	Brazil Block,		48.78	32.34	5.81	13.05	Purdue University. W. F. Goss.		
Great Britain		South Wales			88.3	8.5	3.2	....	Slightly bit. Steam coal. Wilson		1.8
"	"	"			92.3	6.2	1.5	....	Anthracite. No smoke.		
"	"	Wales			83.78	11.35	4.91	....	Haswell's 23d ed., p. 566, 1879		1.43
"	"	Lancashire, Eng			82.6	15.90	1.5	....	Semi-bit. steam coal. Much smoke		0.8
"	"	Lancashire, Eng			80.1	17.20	2.7	....	Bit. gas coal		1.5
"	"	Derbyshire			79.9	17.7	2.4	....	Semi-bit. house and gas coal		0.7

* These substances are frequently taken together as "combustible volatile matter."

TABLE C—(*Continued*).

Country.	Location.	Commercial Name of Coal.	Fixed Carbon.	Volatile matter including carbor, hydrogen, oxygen, nitrogen, sulphur and other volatile substances except water.*	Ash.	Water.	Remarks.	Sulphur.
Great Britain..	Scotland.....	.....	80.1	17.5	2.4	....	Semi-bit. steam coal.....	1.4
" ..	"	.....	63.1	17.1	19.8	....	Bit. Boghead cannel gas coal.....	1.0
" ..	"	.....	78.53	17.41	4.03	....	Haswell's 33d ed., p. 566, 1879.....	1.11
" ..	England.....	Busty Seam, N.E.Eng.	81.22	14.96	3.28	0.85	Upper part of seam coking coals.....	0.81
" ..	"	" "	78.46	15.07	6.17	0.99	Lower " "	1.83
" ..	"	Brockwell Seam, "	83.40	12.58	3.50	0.90	Brockwell seam "	
" ..	"	Newcastle.....	82.10	13.6	3.50	....	R. H. Thurston. Composition of foreign coals..	1.2
" ..	"	Lancashire.....	77.90	17.5	4.60	....	" " "	1.4
" ..	"	Derbyshire.....	79.70	17.6	2.7	....	" " "	1.0
" ..	"	Staffordshire.....	78.6	20.4	1.0	....	" " "	0.4
" ..	Dufferyan.....	.....	88.26	8.54	3.26	....	Haswell's 33d ed., p. 566, 1879.....	1.77
" ..	Cumberland, Eng....	.....	93.81	4.59	1.6	....	" "	
" ..	Northumberl'nd, Eng. and Durham.....	.....	84.3	14.96	0.7	....	Semi-bit. house coal. Wilson.....	1.2
" ..		.....	82.4	14.70	2.9	....	" steam "	1.3
" ..		.....	86.8	15.05	1.1	....	" coking "	0.9
" ..	Vancouver Island....	.....	66.93	17.24	15.83	....	Haswell's 33d ed., p. 566, 1879.....	2.2
South America.	Chili, Conception Bay.	.....	70.55	21.93	7.52	....	" "	1.98
"	" Chiroqui.....	.....	38.98	24.11	36.91	....	" "	6.14
"	"	.....	70.6	22.0	7.4	....	R. H. Thurston. Composition of foreign coals..	2.0
"	Patagonia	.....	62.25	24.35	13.4	....	Haswell's 33d ed., p. 566, 1879.....	1.13
"	Brazil.....	.....	57.9	40.5	1.6	....	R. H. Thurston. Composition of foreign coals.	
Europe	France.....	.....	84.0	14.	2.0	....	" " "	
"	Spain	.....	53.0	40.	7.0	....	" " "	
"	Germany.....	Silesia.....	57.9	42.	2.1	....	" " "	
"	Saxony, Germany....	.....	80.0	19.	1.0	....	" " "	
"	Prussia, "	.....	56.7	18.9	24.4	....	" " "	
Asia.....	Hindoostan.....	.....	50.0	35.4	14.6	....	" " "	
"	Formosa Island.....	.....	78.26	17.78	3.96	....	Haswell's 33d ed., p. 566, 1879.....	0.49
Canada.....	Nova Scotia.....	.....	60.7	26.8	12.5	....	R. H. Thurston. Composition of foreign coals.	
"	Cape Breton.....	.....	67.6	26.9	5.5	....	" " "	
Australia	.....	Lignite.....	64.3	15.8	10.0	....	" " " ..	0.6
"	Sydney, S. Wales.....	.....	82.39	14.98	2.04	....	Haswell's 33d ed., p. 566, 1879.....	0.07
Borneo	.....	.....	70.3	26.5	14.2	....	R. H. Thurston. Composition of foreign coals...	1.2
Australia.....	Van Diemen's Land..	.....	63.4	6.16	30.45	....	Haswell's 33d ed., p. 566, 1879.....	0.98
"	S. Cape Aar'te B.....	.....	80.22	11.11	8.67	....	" "	1.90

* These substances are frequently taken together as "combustible volatile matter."

the efficiency of boilers operated without forcing than under the American plan of operation. The average evaporation per pound of coal used throughout the United States is not over 5½ lbs. of water from and at 212°, while that in foreign countries, when operated between the limits *A* and *B* on the diagram, and which is taken to be the average work, is nearly 10 lbs. These figures correspond to a considerable difference in coal used per square foot of grate per hour; namely, 150 lbs. for the American and about 50 for the foreign.

There is such a wide difference in the evaporating power of the coals found in various parts of the earth, that a comparison of the performance of locomotives using different fuels is well-nigh impossible without a full knowledge of the chemical composition of the fuel used and a practical knowledge of its mechanical action in a locomotive firebox. Coals having much moisture and a large percentage of ash made up of fusible silicates do not give results in evaporation that would be expected from an examination of the chemical composition; and coals having the same percentage of hydrogen, carbon, oxygen, etc., do not necessarily give the same results in evaporation; hence, a practical knowledge of the value of various fuels in locomotive boilers is absolutely necessary before a fair comparison can be made of the relative performance of different engines under otherwise equal conditions.

The varieties of coal in common use and the wide difference in composition may be seen from Table C, but, unfortunately, the real value of the fuels in practical operation cannot be learned from this table, owing to the lack of data recorded by the different experimenters. What is lacking is the real evaporative power of the fuel under equal conditions, and there is much merit in the proposition recently made by one of our engineering societies, to establish a central testing station, with a standard boiler operated under standard conditions, for the purpose of determining the relative value of various fuels.

Perhaps Fig. 7 illustrates as well as need be the reason for the greater economy of foreign locomotives under the conditions of average operation. Of course, if the foreign engine were to be forced so much that the coal used per square foot of grate would increase from 50 to 150, the evaporation would drop from 10 to about 7½; and if the coal used on English engines were no better than that used here, the evaporation would certainly drop to less than 6 lbs. of water per

pound of coal, the same as for the American locomotive. Although there is evidently a waste of coal on the American plan of operating locomotives, yet, as has been shown in the discussion of Fig. 1, there is a gain to the railroad company by doing this. Perhaps the following approximate estimate made up from such accurate data as is now available will give a sufficiently close comparison of the coal used in the best foreign and the best American passenger train service, average coal being taken in both cases :

TABLE D.

Country.	Total train. Weight tons.	Coal per ton mile of total train.	Coal used per square foot grate per hour.	Water evaporated per pound of coal from 212° Fahr.	Coal per ton mile of passenger cars.
Foreign.....	220	.12 lbs.	60 lbs.	9½ lbs.	.182 lbs.
United States...	400	.15 "	110 "	6½ "	.191 "

This comparison shows how little is the difference in the weight of coal used per useful ton-mile here and abroad, under about the same conditions, even when no allowance is made for the difference in the quality of the coal. What this difference in quality amounts to can be seen by an inspection of Fig. 7, on which lines are drawn for the average American and average English coals. With the same coal for both typical locomotives, the American practice of heavy train loads would result in less coal per useful ton mile. In the United States, wages and train expenses other than for coal are so comparatively great as to leave no choice in train practice, and railroads are compelled to condense the passenger traffic into heavily loaded passenger trains run at long intervals in order to pay expenses. There are a few cases here where lighter trains than the average can be run with profit, such as between New York City and Philadelphia; but even there the trains must be heavier than the average foreign train, as more passengers must be carried per train to pay the greater cost of wages and other train expenses. Where parlor and sleeping cars are run, the greater weight of train per passenger also causes heavier train loads. This is seen from Table E.

TABLE E.

GIVING APPROXIMATE DEAD WEIGHT OF CARS PER PASSENGER.

Country.	Type of car.	Number of wheels.	Weight of empty car with trucks.	Number of seats for passengers per car.	Dead weight of car per pass.	Dead weight of cars, locomotive and tender per pass. if seating capacity is taken up.
Foreign.....	.....	4 or 6	30 000	30	1 000	1 538.5
United States..	Sleeper	12	100 000	28	3 571.4	5 312.5
" "	Day coach	8	56 786	62	913.0	1 702.2

There are many other conditions in this country that compel heavy passenger as well as heavy freight trains, and particularly is this true for through trains where the distances are long and the trains cannot be run frequently. Each modern train has a dining car, a baggage car, and frequently one or two mail cars in addition to the cars for passengers. Frequent light trains would not be possible, owing to the great distances between towns and the lack of traffic to pay for the greater cost of train expenses. It is necessary on most roads, in order to regain the cost of running passenger trains, to limit the number of trains and compel the public to wait until the end of business hours, or until railroad connections give a probability of a train load of passengers. Thus it is found in the West that trains leave principal cities mostly at night after business hours. Heavy trains being a necessity, it follows that locomotives must have great starting power, and this has confined American passenger engines to comparatively small wheels.

Small Drivers for Express Service.—We have been frequently criticised severely for the use of 5 and 5½-ft. drivers for express passenger work, but we have no choice. Take, for instance, a 400-ton train to be hauled out of a city like Chicago, having many grade crossings and grades of from 1 to 1½% on the main line on which the train may be stopped. The only possibility of hauling such trains and making the necessary local stops is by using a small wheel and a very powerful engine. When these heavy trains are at speed the resistance is less, as the inertia has been overcome, and not so much weight is thereafter needed on the drivers. After one of our heavy trains is accelerated to speed, a locomotive with 8 or 9-ft. drivers could keep it in motion and

accelerate slowly to a higher speed with greater economy than our present engines; but as we are compelled to use the small drivers in order to start trains and accelerate them, there is no recourse but to use them even for very high-speed locomotives. The maximum rate of acceleration of one of our heavy trains (494 tons) is given in Figs. 22 and 23.

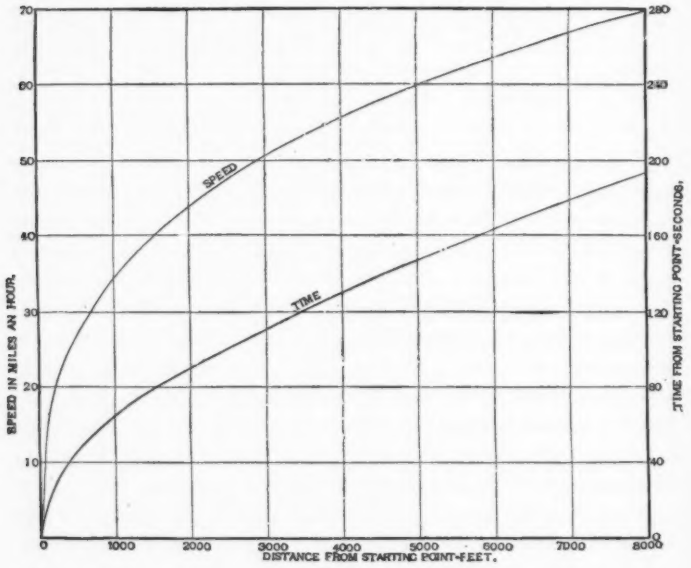

Fig. 22.

Diagram showing the maximum acceleration at different distances from the starting point of an American train of 494 tons, including the locomotive and tender.

The Empire State Express on the New York Central is a good example of the design of locomotive that is compelled by the conditions of operation existing in the United States. This locomotive weighs 64 tons, of which 40½ tons are on the drivers. The wheels are 6½ ft. in diameter and the cylinders 19 × 24 ins. This engine has very much more weight on drivers than is needed to furnish adhesion to haul the train when at high speed; but even with the five-car train, which is the usual load for this engine, there is none too much boiler and cylinder power and weight for use during the accelerating period after leaving stations and to start the five-car train quickly when stopped

on a grade. In any other country wheels at least 8 ft. in diameter would be used for the fast work performed by this engine.

One of the most important factors affecting the size of drivers in the western section of the United States is the necessary policy (for economy) of pooling the heavy passenger engines with the freight engines. This pooling plan contemplates the use of all locomotives in freight service whenever it is advantageous to do so; hence a locomotive may haul a fast passenger train westward for 300 miles and return with a slow and heavy freight or with a through freight on a passenger train schedule. On some roads this pooling plan for engines governs the size of the drivers, as large drivers cannot be used in slow freight service.

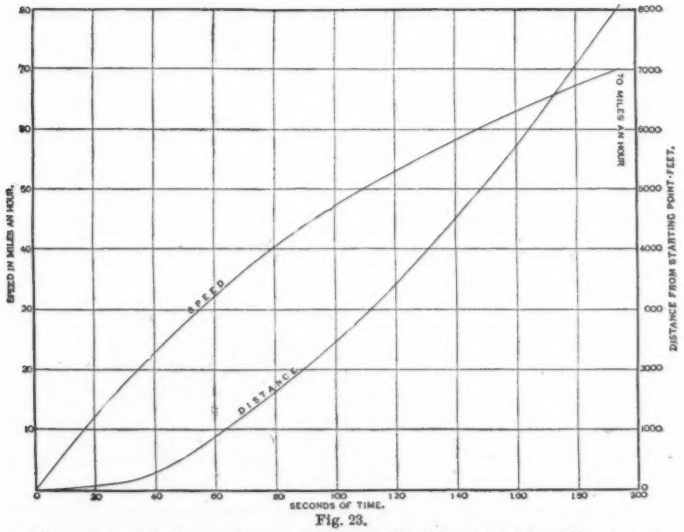

Fig. 23.

Diagram showing the maximum acceleration after different periods of time from the starting point of an American train of 494 tons, including locomotive and tender, when hauled by an American 10-wheel or Mogul locomotive with 47 tons on drivers and when equipped with the most improved valve motion.

To gain adhesion in starting trains, we have been urged to use the sand blast, but no material advance has been made here with that device, not so much from a lack of appreciation of the true value of a sand blast as from the fact that when our engines have boiler power enough to haul our heavy trains with comparative economy there is

found to be sufficient weight on drivers to start the trains without the need of a sand blast, excepting with a slippery rail, and that is provided for here by the sandboxes used. However, the sand blast is more effective than the ordinary sandbox arrangement, and we may expect that future locomotives for higher speeds than are now common in this country will have larger wheels and cylinders than our present types; and will be supplied with the sand blast, if necessary, to give greater adhesion at starting. For high-speed work we shall eventually be compelled to pay more attention to the decrease of total weight of engine and tender to increase the useful train weight; light trains, large wheels and track tanks for water supply are the most necessary conditions for exceedingly high speeds.

The advantages of large driving wheels are well understood here, and much larger wheels would be used if it were practicable to do so. One of the main advantages of a large wheel is the better action of the valve motion. Perhaps this is best shown by Fig. 24, which

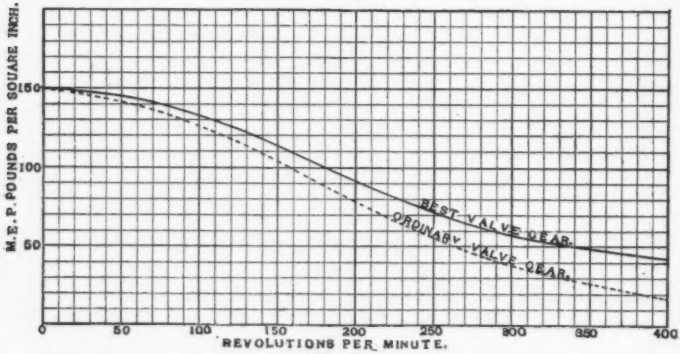

Fig. 24.

Diagram showing the decrease in the maximum mean effective pressure per square inch of piston, with the best and the ordinary valve gears, which follows an increase in the number of revolutions per minute of locomotive driving wheels. Boiler pressure, 175 lbs. per square inch absolute.

gives the reduction of the mean effective pressure in the cylinders of locomotives which accompanies an increase in piston speed. The full line shows the greatest mean effective pressure that has been obtained in any locomotive in this country with a 5½-ft. wheel, with a boiler pressure of 160 lbs. per square inch. This line has been drawn from the results obtained from some indicator cards taken with a special

valve motion which gave a wide opening to the steam port and a very late closing of the exhaust. It practically corresponds with the results obtained on the Reading road with large ports and 7-in. valve travel and 1¼-in. outside lap. The dotted line shows the decrease in the mean effective pressure with the ordinary proportions of Stephenson's link motion used in this and other countries. The variation in mean effective pressure at different speeds resulting from different designs of valve motion is given by the difference between the dotted and full lines. The decrease in the maximum mean effective pressure which accompanies an increase in speed has more bearing upon the possibili-

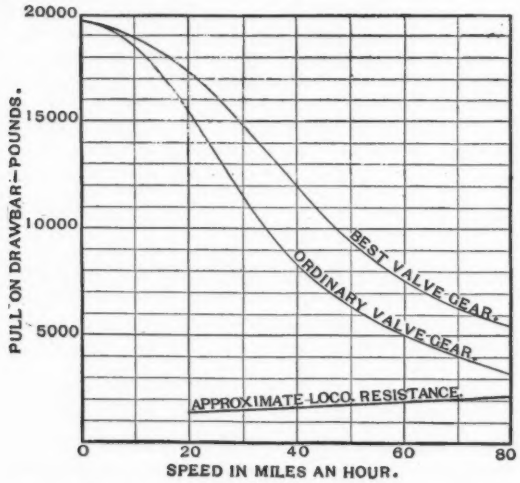

Fig. 25.

Diagram showing the decrease in maximum pull on drawbar which follows an increase in speed of a locomotive with 19 x 24 in. cylinders and 5½-ft. driving wheel.

ties of high speed than any other feature of locomotive design. Even the difficulty of supplying steam for high-speed work has not so much bearing upon the highest attainable velocity of railroad trains as this continual decrease of mean effective pressure. By using large boilers and the best fuel, sufficient steam can be generated to propel trains easily at 100 miles an hour, but it is exceedingly difficult to get a valve motion that will give enough mean effective pressure at 100 miles an hour to overcome the resistance of even a very light train. This is not the result of any material increase in the train resistance

at high speed, but arises almost solely from the reduction of cylinder power caused by the inadequacy of the valve gear and cylinder apparatus to maintain the same propelling power at high speed that is readily produced at moderate speed.

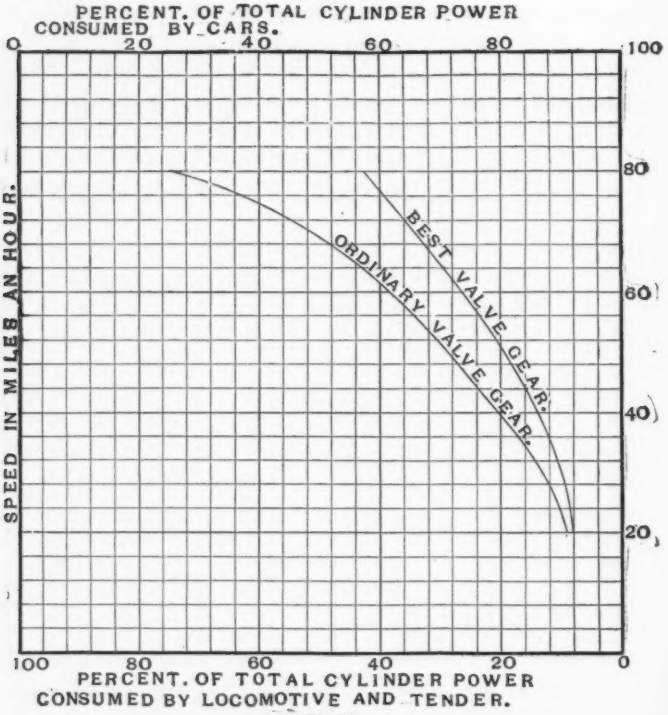

Fig. 26.

Diagram showing the increase of the percentage of cylinder power consumed by locomotive and tender which necessarily follows an increase of speed independent of any change there may be in train resistance.

Fig. 25 shows the decrease of hauling power as the speed is increased, both with the best and the ordinary valve gear. Fig. 26 shows the percentage of the power used by the locomotive and tender and that remaining to haul the cars at different speeds. This shows clearly that the rapid decrease of the power available for hauling cars is the prime cause of the difficulty of running heavy trains at high velocity. It is not, as has been claimed, caused by the rapid increase

in the resistance of the train resulting from head air resistance, suction of air at the rear, concussion, oscillation and other unimportant factors.

With a given valve motion, the speed in revolutions per minute almost wholly controls the highest attainable mean effective pressure in the cylinders. The greater the revolutions per minute, the less will be the mean effective pressure; hence the logical conclusion is that a larger driving wheel should be used for high-speed work. The effect of large driving wheels on the mean effective pressure is emphatically shown by Fig. 27, on which are drawn curves, indicating the

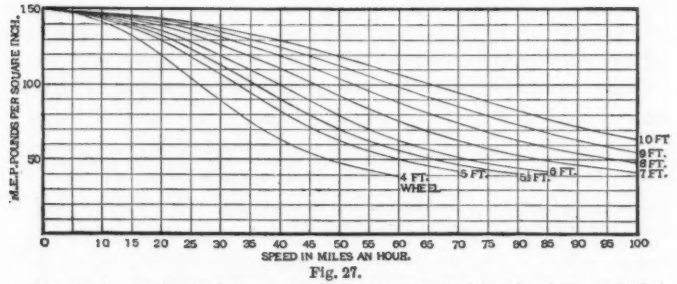

Fig. 27.

Diagram showing the maximum mean effective pressure on piston at various speeds that can be obtained with different diameters of driving wheels when steam valves are controlled by any of the existing types of link motion. Boiler pressure 175 lbs. per square inch (absolute).

variation of mean effective pressure at different speeds with different wheel diameters. From this, one would say immediately, Why not use 10-ft. drivers? But the answer comes at once; it is impossible to do so under conditions of American railroad operation except for special trains on which a large extra fare can be charged. The cost of running such a train as could be hauled by a locomotive having drivers 10 ft. in diameter is as great as the cost of running a slower one with many more cars, and the consequential cost of side-tracking freight trains and slower passenger trains is very great; and these, taken together with the greater risk of serious collisions, show why it is practicable only in a very few special cases, if any, to run trains in this country at a speed that would require 10-ft. drivers. Therefore, great as the advantages in steam use might be with larger drivers, the necessarily heavier loads in this country at the present time compel the smaller wheel.

Small drivers for high speed is a marked feature of American locomotive practice, and one that has many advantages in a new country

with long distances. The maximum speeds here are as high as in any other country, and the maximum average speeds for long distances are higher here than anywhere else, but we have not the same number of fast trains in proportion to the total number of trains as in England, but have more than the average on the continent of Europe. At the present rate of development of train service between New York and Chicago, the fastest and heaviest passenger trains on earth will be run in the United States ; but we have much to do in the development of locomotive design before the most practical locomotive for such service will be had. Larger wheels and cylinders, higher steam pressure and less dead weight of engine and tender, will probably be the lines that will be followed in gaining the best locomotive for this service.

Compound Locomotives.—American compound locomotives are almost exact counterparts in the compound features of those used in Europe, the single exception to this being the Vauclain and the Johnstone types. More than 400 of the Vauclain type have been built by the Baldwin Locomotive Works. So far, no marked advantage in fuel saving has been obtained from the use of compounds in this country in fast passenger service. This arises from the bad action of the valve motions used, it being more difficult to design a suitable steam regulating mechanism for compound locomotives on account of the greater back pressure in the high-pressure cylinder, particularly when small drivers are used. In freight and suburban service, where the single-expansion engine uses steam with less expansion than in faster work, the compounds of all types have given a reduction of from 12 to 40% in fuel. At this time, the development of the compound locomotive is so rapid that what is now a true general statement may within a year's time be shown to apply only to the narrow limits of present designs.

Duplication of Parts.—The cost of labor in the drafting room, the need of quick deliveries and the prevailing practice of contracts with individual mechanics, puts a premium on duplication and interchangeability of parts, and the result is that the locomotives of each prominent manufacturer in this country have many duplicate parts and dimensions, even when the general dimensions of the engines differ widely. This practice leads to low first cost and rapid construction, and to some extent aids in the universal endeavor to gain simplicity. The defect of it is found in the temptation to use too small details for the larger engines, and too large parts for the smaller ones. However

Name of Railroad Company.	Number of drivers.	Number of front truck wheels.	Number of rear truck wheels.	With or without separate tender.	Inside or outside cylinders.	Single expansion or compound.	Diameter of driving wheels. Inches.	Siz
C. M. & St. P.	4	4	0	With	Outside	Single Expansion	62	
New So. Wales	6	4	0	"	"	"	61	
C. R. R. of N. J.	4	4	0	"	"	"	68	
B. & O.	6	4	0	"	"	"	62	
C. C. C & St. L.	6	4	0	"	"	"	66	
Penn. R. R.	4	4	0	"	"	"	78	
N. Y. C. & H. R.	4	4	0	"	"	"	84	
C. B. & Q.	4	4	0	"	"	"	6[illegible]	
N. Y. C. & H. R.	4	4	0	"	"	"	78	
C. C. C. & St. L.	4	4	0	"	"	"	68	
N. Y., L. E. & W.	6	4	0	"	"	"	68	
M. C.	6	4	0	"	"	Schenectady Compound	74	2
Penn. R. R.	6	4	0	"	"	" " "	74	2
C. R. R. of N. J.	4	4	0	"	"	Vauclain Compound	78	1
Penn. R. R.	6	4	0	"	"	" " "	72	1
Phila. & Reading	4	2	2	"	"	" " "	78	1
C., B. & Q.	6	2	0	"	"	C. B. & Q. Compound	62	2
C., M. & St. P.	6	4	0	"	"	Rhode Island Compound	78	2
W. N. Y. & Pa.	8	2	0	"	"	Single Expansion	50½	
B. & M.	10	0	0	"	"	"	50	
C. C. C. & St. L.	6	4	0	"	"	"	56	
B. & O.	8	2	0	"	"	"	50	
"	6	4	0	"	"	"	60	
D. & I. R.	8	4	0	"	"	"	54	
W. N. Y. & Pa.	8	2	0	"	"	Vauclain Compound	50½	1
So. Pacific	6	4	0	"	"	Schenectady Compound	55	2
N. Y., L. E. & W.	10	2	0	"	"	Vauclain Compound	50	1
Cornwall & Lebanon	8	2	0	"	"	" " "	50	1
C., M. & St. P.	4	4	0	"	"	" " "	62	1
Illinois Central	6	2	0	"	"	Rogers Compound	56½	2

NOTE.—The formula from which column marked "Ratio of cylinder power to weight available for adhesion,"

(Ratio of cylinde

NOTE.—Where the boiler pressure could not be determined from the description of the locomotives, as given
For compound locomotives the figures in the last column of ratios are based on the capacity of the low-press
power of single expansion and compound locomotives.

TABLE A1.

Giving Dimensions of American Locomotives.

xpansion or pound.	Diameter of driving wheels. Inches.	Size of cylinders. Inches.	Total weight of engine. Pounds.	Total weight on driving wheels. Pounds.	Total weight on trucks. Pounds.	Weight of tender loaded. Pounds.	Area of Grate. Square feet.	Firebox heating surface.
nsion.....	62	16 x 24	86 000	54 000	32 000	63 000	15.5	113
.....	61	21 x 24	130 000	97 500	32 500	72 000	24.9	105
.....	68	19 x 24	105 900	75 900	30 000	{ 41 000 / Empty }	37.	.....
.....	62	21 x 26	133 000	103 300	29 700	{ 35 100 / Empty }	28.2	188
.....	66	18½ x 24	131 400	102 800	28 600	76 800	18.2	147
.....	78	19 x 24	123 000	81 000	42 000	87 050	26.2	144
.....	84½	19 x 24	123 000	82 200	40 800	80 500	27 3	.....
....	67½	18 x 24	.....	66 600	....	.....	24.5	111
.....	78	19 x 24	126 150	81 400	44 750	81 750	27.3	147
.....	68	18½ x 24	129 280	86 500	42 780	85 280	31.3	143
.....	68	20 x 24	113 000	100 000	30 000	76 000	.....	186
Compound....	74	20 and 29 x 24	135 000	99 000	36 000	{ 31 000 / Empty }	28.2	141
"	74	20 and 30 x 24	138 000	102 000	36 000	87 050	26.2	141
mpound.....	78	13 and 22 x 24	123 800	88 400	35 400	.....	28.5	.....
"	72	14 and 24 x 24	133 000	100 000	33 000	.....	28.3	.....
"	78	13 and 22 x 24	129 000	83 000	46 000	.....	76	128
mpound.....	62	20 and 29 x 24	115 000	98 000	17 000	.....	27.1	126
d Compound..	78	21 and 31 x 26	143 000	88 500	54 500	75 000	.....	.....
usion.....	50½	19 x 26	126 870	110 650	16 220	.....	29.	.....
.....	50	22 x 28	150 300	150 300	....	.....	37.5	180
.....	56	19 x 24	128 200	99 600	28 600	76 800	18.2	147
.....	50	21 x 26	125 000	113 400	11 600	....	28.7	153
.....	60	20 x 26	127 500	101 500	26 000	.....	32.5	140
.....	54	19 x 24	16 900	96 000	33 000	{ 31 000 / Empty }	34 5	169
mpound.....	50½	13 and 21 x 26	129 600	116 550	13 050	.....	29.	.....
Compound....	55	20 and 28 x 26	126 000	99 500	26 500	.....	24.6	141
mpound.....	50	16 and 27 x 28	193 000	170 000	23 000	.....	.....	182
"	50	14 and 24 x 28	150 000	135 000	15 000	.....	33.3	.....
"	62	12 and 20 x 26	122 400	87 970	34 430	.....	18.2	.....
ound.....	56½	20 and 29 x 26	128 500	107 300	21 200	.....	24.1	.....

eight available for adhesion," is calculated as follows:

$$\frac{2 \times \text{cylinder area} \times \text{boiler pressure} \times \text{stroke}}{\text{Weight on drivers} \times \text{diameter of driving wheel.}}$$

(Ratio of cylinder power of compound engines cannot be compared with that of the single exp
of the locomotives, as given by the builders and operators of the locomotives, it has been assumed to be
the capacity of the low-pressure cylinders only, the volume of the high-pressure being omitted. This h

Firebox heating surface. Square feet.	Tube heating surface. Square feet.	Diameter of shell of boiler. Inches.	Boiler, wagon top, Belpaire or straight.	Steam pressure per square inch atmospheric. Pounds.	Length of tubes. Feet and inches.	Diameter of tubes. Inches.	Description of service for which engine is built.	Capacity of water tank. Gallons.	Coal capacity. Pounds.	Ratio of cylinder power to weight, available for adhesion.
					Ft. Ins.					
115.	801	44	Wagon.....	160	11 0	2	Passenger	3 200	10 000	0.461
105.	1 821.5	62	Straight.....	160	.....	.....	"	3 600	.....	0.447
.....	.....	.....	Wagon.....	160	11 9½	2	"	.....	.....	0.421
188.5	1 846.8	64	"	160	13 2½	2¼	"	.....	.....	0.450
147.	1 883.4	60	"	160	13 4½	2	"	3 700	14 000	0.304
144.3	1 672.2	58	"	180	12 0	2	"	3 500	16 000	0.387
.....	.....	58	"	180	12 0	2	"	3 587	14 500	0.352
111.	1 301	56	Straight.....	160	.....	.....	"	.....	.....	0.426
147.7	1 670.7	58	Wagon.....	180	12 0	2	"	3 500	13 500	0.385
143.7	1 426.3	59	{ Straight } Belpaire }	180	11 4	2	"	4 000	14 000	0.395
186.	1 885	60	Wagon.....	160	12 2	2	"	3 600	.....	0.355
141.2	1 839.5	58	"	180	13 0	.....	"	3 800	16 000	0.389
141.7	1 811.5	58	"	180	13 0	2	"	3 500	16 000	0.404
.....	.....	58	"	180	11 10	2	"	3 500	.....	0.476
.....	.....	62	Straight	180	14 0	2	"	3 600	.....	0.542
128.9	1 261.7	.....	Wootten.....	170	10 0	1½	"	.....	.....	0.423
126.	1 380	56	"	160	.....	.....	"	.....	.....	0.417
.....	.....	62	Wagon.....	200	12 8⅝	2	"	4 000	.....	0.554
.....	.....	.....	Straight.....	160	12 1⅝	2	Freight ..	.....	.....	0.424
180.	2 171	68	"	160	14 6	2⅛	" ..	3 480	.....	0.483
147.	1 883.4	60	Wagon.....	160	13 4½	2	" ..	3 700	14 000	0.301
155.	1 584	55	"	160	13 7	2⅛	" ..	.....	.....	0.507
146.2	1 608	60	Straight.....	180	13 0	2⅛	" ..	.....	.....	0.482
189.7	2 212.6	72	"	180	13 6	2¼	" ..	3 500	13 000	0.472
.....	.....	.....	"	175	12 11½	2	" ..	.....	.....	0.538
141.2	1 788.3	60	Wagon.....	180	13 0	2¼	" ..	4 000	16 000	1.525
182.5	2 208	.....	Wootten.....	175	12 0	2	" ..	4 500	.....	0.660
.....	.....	72	Straight.....	180	13 6	2¼	" ..	3 600	.....	0 675
.....	.....	.....	.....	175	13 7½	2⅛	" ..	.....	.....	0.525
.....	.....	.....	Belpaire.....	180	11 0	2	" ..	3 500	.....	0.512

gle expansion engines.)

o be 160 lbs. per square inch above the atmosphere.

This has been done for the purpose of comparison, and because there is no accurate simple way of comparing the cylinder

Name of Railroad Company.	Number of drivers.	Number of front truck wheels.	Number of rear truck wheels.	With or without separate tender.	Inside or outside cylinders.	Compound or single expansion.	Diameter of driving wheels. Inches.	Si
Great Northern	2	2	2	With.....	Inside ...	Single Expansion...	91½	
London and North West.	4	2	2	"	Outside ..	Webb Compound,...	85	
North London	4	4	0	"	Inside ...	Single Expansion...	71	
" "	4	4	0	"	Outside..	" ...	65	
Bristol and Exeter	2	4	4	Without..	Inside ...	" ...	108	
Great Western	2	4	2	With.....	" ...	" ...	96	
Midland	4	2	0	"	" ...	" ...	84	
"	2	4	2	"	" ...	" ...	90	
London and So. Western	4	4	0	"	Outside ..	" ...	79	
Midland	4	4	0	"	Inside ...	" ...	84	
London B and So. C.	4	2	0	"	" ...	" ...	78	
London and N. W.	4	2	0	"	Outside ..	Webb Compound....	85	1
" " "	2	4	2	"	" ...	"	72	1
Highland	4	4	0	"	" ..	Single Expansion...	68½	
North Eastern	4	0	4	Without..	Inside ...	" ...	60	
Caledonian	2	4	2	With.....	" ...	" ...	84	
Great Western	2	2	2	"	" ...	" ...	92	
North British	4	4	0	"	" ...	" ...	84	
" "	4	4	0	"	" ...	Tandem Compound.	79	1
Caledonian	4	4	0	"	" ...	Single Expansion...	78	
Glasgow and So. W.	4	4	0	"	" ...	" ...	73½	
North Eastern	2	4	2	"	" ...	Worsdell Compound.	91½	2
" "	2	4	2	"	" ...	" .	85½	1
South Eastern	4	4	0	"	" ...	Single Expansion...	84	
Waterford and Limerick	4	2	0	"	" ...	" ...	72	
Great Eastern	2	4	2	"	Outside ..	" ...	90	
London and N. W.	4	2	0	"	" ..	Webb Compound....	.....	11
North British	4	4	0	"	Inside ...	Single Expansion...	42	
" Eastern	4	0	4	Without..	" ...	" ...	60	
L. C. and D.	4	0	4	" ..	" ...	" ...	63	
London and N. W.	4	2	0	With.....	Outside..	Webb Compound....	75	1
Great Western	2	2	2	"	Inside ...	Single Expansion...	92½	
" Northern	2	2	2	"	" ...	" ...	90	
" "	4	2	0	"	" ...	" ...	78	
" "	2	4	2	"	Outside ..	" ...	96	
Man., Shef. and Lincolnshire	4	4	0	"	Inside ...	" ...	81	
London, B. and So. C.	2	2	2	"	" ...	" ...	78	
London and N. W.	4	2	0	"	" ...	" ...	81	
Great Eastern	4	2	0	"	" ...	" ...	84	
London and Brighton	4	0	2	"	" ...	" ...	78	
London and N. W.	4	2	0	"	Outside ..	Webb Compound....	73	1
Midland	4	2	0	"	Inside ...	Single Expansion...	80	
North London	6	0	0	"	Outside..	" ...	52	
Cornwall Mineral	6	0	0	"	" ..	" ...	42	
So. Eastern	6	0	0	"	Inside ...	" ...	61	
London and N. W.	6	0	0	"	" ...	" ...	60	
Great Eastern	6	0	0	"	" ...	Worsdell Compound.	58	1
Midland	6	0	0	"	" ...	Single Expansion...	62½	
L. B. and S. C.	6	0	0	"	" ...	" ...	47½	
Great Eastern	6	2	0	"	Outside ..	" ...	5[illegible]	
" "	6	0	0	"	" ...	" ...	58	
Lancashire and Yorkshire	6	0	0	"	Inside ...	" ...	60½	
Tilbury and South End	4	4	2	Without..	Outside..	" ...	73	
Great Northern	6	0	0	With.....	Inside ...	" ...	60	
" "	4	0	2	"	" ...	" ...	66	
London and N. W.	8	0	0	"	Outside..	" ...	53½	
Great Eastern	4	2	0	"	" ..	" ...	68	
Barry	6	0	2	Without..	Inside ...	" ...	51	
L. and S. W.	4	0	2	With.....	" ...	" ...	72	

NOTE.—The formula from which column marked "Ratio of cylinder power to weight available for adhesion"

(Ratio of cyl

NOTE.—Where the boiler pressure could not be determined from the description of the locomotives, as given b

For compound locomotives the figures in the last column of ratios are based on the capacity of the low-pres
cylinder power of single expansion and compound locomotives.

TABLE No. A2.

Giving Dimensions of Locomotives in Great Britain.

nd or single ansion.	Diameter of driving wheels. Inches.	Size of cylinders. Inches.	Total weight of engine. Pounds.	Total weight on driving wheels. Pounds.	Total weight on trucks. Pounds.	Weight of tender, loaded. Pounds.	Area of grate. Square feet.	Firebox heating surface. Square feet.
Expansion...	91½	18½ x 26	91 056	38 976	52 080	86 240	18.4	108.7
mpound,...	85	15 and 30 x 24	116 480	69 440	47 264	56 000	20.5	129.6
Expansion...	71	17½ x 24	100 800	69 440	31 360	.....	16.62	91
" ...	65	17 x 24	103 124	72 968	30 156	.....	16.62	91
" ...	108	16½ x 24	94 080	47 040	47 040	.....	.....	.....
" ...	96	18 x 24	93 408	35 840	57 568	67 200	24	153
" ...	84	19 x 26	95 900	62 664	33 286	.....	17.5	110.16
" ...	90	19 x 26	96 320	39 200	57 120	.....	19.6	117
" ...	79	18 x 24	104 720	67 648	37 072	78 400	17.7	110.18
" ...	84	18 x 26	.....	.....	.....	.....	.....	.....
" ...	78	18½ x 26	86 700	63 450	23 250	61 150	21	114
mpound....	85	14 and 30 x 24	103 600	70 560	33 040	.....	20.5	150.1
"	72	12 and 24 x 24	84 200	.....	.....	47 600	15.13	120.2
Expansion...	68½	18 x 24	96 320	.....	.....	71 680	18.8	97.5
" ...	60	16 x 22	.....	.....	.....	.....	.....	.....
" ...	84	18 x 26	93 856	38 080	55 776	75 040	.....	.....
" ...	92	18 x 26	.....	.....	.....	.....	19.23	130
" ...	84	18 x 26	91 400	.....	.....	71 680	21	119
Compound.	79	13 and 20 x 24	.....	.....	.....	.....	.....	.....
Expansion...	78	19 x 26	100 960	68 200	32 760	78 100	19.5	122
" ...	73½	18½ x 26	93 000	62 200	30 800	60 480	16	101
l Compound.	91¾	20 and 28 x 24	104 550	39 760	64 790	89 700	20.7	123
" .	85¾	18 and 26 x 24	96 040	40 320	55 720	75 712	17 23	110
Expansion...	84	19 x 26	92 960	62 944	30 016	68 320	16.78	105.5
" ...	72	17 x 24	81 676	75 328	26 348	50 300	18	110
" ...	90	18 x 24	105 760	43 600	62 160	.....	17.1	111
mpound....	....	11½ and 26 x 24	.....	.....	.....	.....	.....	.....
Expansion...	42	17 x 26	.....	.....	.....	.....	.....	.....
" ...	60	16 x 22	.....	.....	.....	.....	.....	.....
" ...	63	17½ x 26	.....	.....	.....	.....	16.5	.....
mpound....	75	14 and 30 x 24	95 200	67 200	28 000	56 238	20.5	159.1
Expansion...	92½	20 x 24	98 560	42 560	56 000	.....	20.8	124
" ...	90	18½ x 26	91 056	38 976	52 080	90 244	18.4	109
" ...	78	17½ x 26	87 360	61 600	25 760	90 244	16.25	92.4
" ...	96	18 x 28	101 136	38 080	63 056	90 244	17.75	109
" ...	81	18 x 26	103 040	71 792	31 248	78 400	18.85	99
" ...	78	17 x 24	74 800	30 250	44 550	.....	17	100
" ...	81	17 x 24	74 360	50 400	23 960	55 000	17.1	103.5
" ...	84	18 x 24	94 108	61 746	32 312	72 800	17.9	.....
" ...	78	18 x —	.....	.....	.....	.....	.....	.....
ompound....	73	15 and 26 x 24	84 560	61 264	23 296	.....	17.1	103.5
Expansion...	80	17 x 24	85 568	58 912	26 656	.....	17.5	110
" ...	52	17 x 24	98 392	98 392	0	.....	16.33	81
" ...	42	16½ x 20	67 880	67 880	0	.....	.....	70.7
" ...	61	18 x 26	70 830	70 830	0	.....	.....	95.25
" ...	60	17 x 24	63 168	63 168	0	.....	15	87.3
l Compound.	58	18 and 26 x 24	88 300	88 300	0	.....	17.9	105
Expansion...	62½	17½ x 26	84 952	84 952	0	.....	17.5	110
" ...	47½	13 x 20	54 544	54 544	0	.....	10	55
" ...	54	19 x 26	104 384	85 344	19 040	62 832	17.8	102
" ...	68	17½ x 24	81 800	81 800	0	.....	17 9	105.5
" ...	60⅞	18 x 26	94 416	94 416	0	.....	18.75	107.68
" ...	73	17 x 24	126 336	71 820	54 516	.....	17	97
" ...	60	17½ x 26	81 760	81 760	0	78 260	16.25	92.4
" ...	66	17½ x 24	78 624	60 032	18 592	78 512	16.25	92 4
" ...	53½	19½ x 24	104 916	104 916	0	56 000	20.5	114.7
" ...	68	17½ x 24	90 300	31 700	58 600	.....	18	101
" ...	51	18 x 26	126 560	.....	.....	.....	20.75	110
" ...	72	18 x 26	95 984	72 128	23 856	67 424	17	116.7

ght available for adhesion " is calculated as follows:

$$\frac{2 \times \text{cylinder area} \times \text{boiler pressure} \times \text{stroke}}{\text{Weight on drivers} \times \text{diameter of driving wheels.}}$$

(Ratio of cylinder power of compound engines cannot be compared with that of the single
f the locomotives, as given by the builders and operators of the locomotives, it has been assumed to be 160
the capacity of the low-pressure cylinders only, the volume of the high-pressure being omitted. This ha

N.

Surface. Square feet.	Tube heating surface, square feet.	Diameter of shell of boiler. Inches.	Boiler, wagon top, Belpaire or straight.	Steam pressure per square inch atmospheric. Pounds.	Length of Tubes. Feet and Inches.	Diameter of Tubes. Inches.	Description of service for which engine is built.	Capacity of water tank. Gallons.	Coal capacity. Pounds.	Ratio of cylinder power to weight available for adhesion.
					Feet. Inches.					
3.7	1 001	50	Straight..	160	11 9	1¾	Passenger	.....	.....	0.627
9.6	1 346	51	" ..	175	10 1	2⅛	"	.....	.....	0.503
	1 050.7	50	" ..	160	.....	1¾	"	1 320	2 800	0.374
	860	50	" ..	180	10 ⅞	1¾	"	1 020	2 800	0.413
	.....	48.5	" ..	160	11 2	1⅝	"	.....	.....	0.323
3	1 598	54	.....	160	11 1	2	"	3 000	.....	0.567
0.16	1 011.46	51	Straight..	160	10 6	(1½ (1¾	"	3 900	.....	0.448
7	1 123.5	50	" ..	160	10 4	(1½ (1⅝	"	3 900	7 840	0.669
0.18	1 051.13	52	" ..	160	10 8	1¾	"	2 800	7 840	0.366
.....	..	.....	" ..	160	.....	.....	"	.....	.....	.....
4	1 386	53	" ..	150	10 2	1½	"	2 250	.....	0.412
0.1	1 212	.....	" ..	175	.....	1⅞	"	.....	.....	0.495
0.2	911.7	.....	" ..	120	.....	.....	"	1 440	170 cu. ft.	
7.5	1 038.5	50	" ..	.....	10 4	1¾	"	2 250		
...	.....	50.5	" ..	.....	10 9¼	2	"	9 0		
.....	.....	51	" .	120	10 7	1¾	"	2 850	.....	0.621
0	1 120	51	" ..	150	10 11¼	1⅝	"			
9	983	52	" ..	.....	10 7⅝	1¾	"	2 550	11 200	
.....	.....	.....	" ..	.....	.....	.....	"	.....	.....	.....
2	1 047.2	52	" ..	160	10 1½	1¾	"	3 408	11 200	0.443
1	845	50	" ..	140	10 11⅛	1¾	"	2 5?0	7 000	0.417
3	1 016	51	" ..	175	10 11	1¾	"	3 940	8 960	0.713
0	1 0.6	51	" ..	175	10 11½	1¾	"	3 138	8 960	0.547
5.5	917	52	" ..	150	10 ⅛	1⅝	"	2 650	8 960	0.418
0	1 000	.....	" ..	150	.....	.....	"	2 000	7 840	0.410
1	1 037	49	" ..	140	.....	1¾	"	3 000	.....	0.436
.....	.....	.....	" ..	.....	.....	.....	"	.....	.....	.....
.....	.....	52	" ..	150	10 8	1¾	"	950		
.....	.....	.....	" ..	.....	10 9¾	.....	"	960		
.....	.....	51	" ..	.....	11 3	1¾	"	963		
9.1	1 118.1	49	" ..	175	.....	1⅞	"	2 160	11 200	0.584
4	1 321	50.1	Wagon...	160	11 9¼	1⅝	"	3 000	.....	0.613
9	936	50	Straight..	160	.....	1¾	"	.....	.....	0.638
2.4	836.9	50.5	" ..	160	.....	1¾	"	3 500	11 200	0.417
9	936	50	" ..	160	.....	1¾	"	3 500	11 200	0.624
0	1 179	51	" ..	160	11 ⅝	1¾	"	3 000	.....	0.363
0	1 084	51	" ..	160	10 6	1⅞	"	2 250	4 4 0	0.738
3.5	961	49	" ..	160	.....	.....	"	.....	.....	0.427
.....	.....	52	" ..	140	10 4	1⅛	"	2 640	4 500	0.329
.....	.....	53	" ..	.....	9 10	.....	"	2 250	.....	.....
3.5	980	49	" ..	175	10 1	1⅞	"	.....	.....	0.467
0	1 115	49	" ..	160	10 11	1¾	"	2 000	.....	0.369
1	875.85	50	" ..	160	9 11¼	1¾	Freight..	1 147	2 800	0.340
0.7	752.8	.....	" ..	150	.....	1⅝	" ..	1 560	.....	0.450
5.25	1 034	51	" ..	150	.....	1⅝	" ..	.....	.....	0.459
7.3	981	.....	" ..	160	.....	1⅞	" ..	.....	.....	0.460
5	1 109	52	" ..	175	10 4	1⅝	" ..	.....	.....	0.435
0	1 203	51	" ..	150	.....	1¾	" ..	.....	.....	0.353
5	470	.....	" ..	140	8 3¼	1¾	" ..	.....	.....	0·287
2	1 291	51⅛	" ..	140	11 9⅛	1¾	" ..	2 600	. .....	0.417
5.5	1 055	52	" ..	140	10 4	1¾	" ..	3 680	11 200	0.341
7.68	1 102.2	49	" ..	160	10 9¾	1¾	" ..	.....	.....	0 369
7	914	49	" ..	160	.....	1⅝	" ..	1 300	4 480	0.332
2.4	830	50½	" ..	160	.....	.....	" ..	2 800	11 200	0.408
2 4	823.6	50½	" ..	160	.....	1¾	" ..	2 800	11 200	0.467
4.7	1 091.5	51	" ..	160	.....	2⅛	" ..	.....	.....	0.409
91	1 107	52	" ..	160	10 4	1⅝	" ..	3 080	.....	0.858
10	1 023	52	" ..	.....	.....	2	" ..	1 750	3 5?4	
6.7	1 131.4	52	" ..	160	11 4	1¾	" ..	3 000	.....	0.407

single expansion engines.)

be 160 lbs. per square inch above the atmosphere.

This has been done for the purpose of comparison, and because there is no accurate simple way of comparing the

TABLE A3.

Giving Dimensions of Locomotives in Other Countries.

Name of Railroad Company.	Number of driving wheels.	Number of front truck wheels.	Number of rear truck wheels.	With or without separate tender.	Inside or outside cylinders.	Single expansion or compound.	Diameter of driving wheels. Inches.	Size of cylinders. Inches.	Total weight of engine. Pounds.	Weight on driving wheels. Pounds.	Weight on truck wheels. Pounds.	Weight of tender, loaded. Pounds.	Area of grate. Square feet.	Firebox heating surface. Square feet.	Tube heating surface. Square feet.	Diameter of boiler. Inches.	Boiler, wagon top, Belpaire or straight.	Steam pressure. Pounds per square inch.
Western R. R. of France	4	2	0	With	Inside	Single Expansion	78½	17 x 23.5		59 000				76	1 156	47	Straight	127
" "	6	0	0	Without	"	"	60.6	16.9 x 23.6	83 000	83 000				11.7	81.8	983.2	48	142
" "	4	4	0	With	"	"	80.5	18 x 26	106 773	65 333	41 400			19			49	Wagon	156
" "	4	2	0	"	"	"	82.5	17 x 24		58 000				25	98	1 241	49	Straight	140
" "	4	2	0	"	"	"	80 3	17.2 x 24	86 688	60 033	26 656			17.6	103.3	1 0-6.7	48.4	"	142
French State	4	2	2	"	"	"	79.5	17.6 x 26	96 544	60 480	36 064			17.6	95.7	1 197.5	48	"	170
Paris, Lyons and Med	4	2	2	"	Outside	4-Cylinder Compound	78.7	19.7 and 12.2 x 24.4	117 947					25.2			49.7	"	213
" "	4	2	2	"	"	Single Expansion	82.5	19.5 x 25.5		60 000				22	96	1 447		"	140
" "	4	2	2	"	"	2-Cylinder Compound	78.7	12.4 and 20 x 24.8	118 840	66 304	52 536			25.2	124.7	1 059.9	49.6	"	213
" "	4	4	0	"	"	4-Cylinder Compound	77.6	13.4 and 21.2 x 24.4	107 520	67 200	40 320			25				Wagon	215
" "	4	2	2	"	Out and Inside	"	78.7	12.2 and 19.6 x 24.4	117 700	65 120	52 580	80 520		25.2	125	1 160.6	50.7	"	180
Paris and Orleans	4	2	2	"	Outside	Single Expansion	78.7	19.6 x 24.4	111 100	62 810	48 290			24.1	112.9	1 422.5	50.7	"	156.2
" "	4	2	2	"	"	"	80	17 x 25.5		56 320				16.3	112	1 532		Straight	127
" "	4	2	2	"	Inside	"	84.6	18 x 28	122 528	70 336	52 192			23.3	152.8	1 326.7	49.2	"	185
" "	4	2	2	"	Out and Inside	"	78.7	17.7 x 27.5	120 340	69 080	51 260	74 030		23.1	152.6	1 326.6	49.2	Wagon	184.6
Northern R. R. of France	6	2	0	"	Outside	"	55	18.9 x 23.6	113 300	86 020	27 280	45 672		18.7	126.9	6 411.4	59	Straight	156.2
" "	4	2	0	"	"	"	68.5	15 x 22	67 000	46 050	20 950		9.47	51.67	726.7			
" "	4	4	0	"	"	"	83 8	18.9 x 23.6	86 400	53 800	32 600			118.4	1 044.1	49.2	"	
" "	4	2	0	"	Inside	4-Cylinder Compound	84	18.4 and 13.2 x 24.4	84 672	61 724	22 948		24.4	102.2	1 005	48	"	156
" "	4	4	0	"	"	Single Expansion	83.8	19.4 x 24	98 768	60 256	36 512		21.9	148.5	1 043.7	49.2	"	170
" "	4	4	0	"	Outside	4-Cylinder Compound	83.2	13.4 and 20.9 x 25.6	105 350	67 220	38 130	74 050	21.9	146.7	1 054.8	49.8	"	190
" "	4	4	0	"	"	"	83	13.5 and 21 x 25	105 280	67 200	38 080		21.9	116.9	1 065.2	49.5	"	182
" "	4	4	0	"	"	"	83.2	13.4 and 20.9 x 25.2	105 380	67 240	38 140		22	117	1 094.5	49.6	"	199
Southern R. R.	4	2	0	"	Out and Inside	"	82.6	13.1 and 13 x 24	74 401				24.4			52.2	"	156.4
Eastern R. R.	4	4	0	"	Outside	Single Expansion	78.7	17.6 x 24	95 872	67 200	28 672		18.4	104.4	1 098.6	50.4	"	142
" "	4	2	0	"	"	"	82.2	19.7 x 26	122 950	72 150	50 800		26	170.7	1 768.5	31.5 & 47.5	Double barrel	
" "	4	4	0	"	Inside	"	80.3	16.9 x 24.6	85 250	58 960	26 290		17.6	103.3	1 086.7	51.8	Straight	142
Paris and St. Germain	6	0	0	"	"	"	80.3	18.1 x 25.9	105 160	64 460	40 700		19	107.6	4 913.3	52.4	"	156.2
Paris, Lyons and Med	8	0	0	"	Out and Inside	4-Cylinder Compound	60.5	17 x 23.5	69 440				17	75	1 035		"	143
" "	8	0	0	"	"	"	59	21.3 and 13.4 x 25.6	125 444				25.5			55.1	"	213
" "	8	0	0	"	"	"	49.5	21.5 and 14.2 x 25.6	125 883				23.5			59	"	213
" "	8	0	0	"	"	"	49.6	14.4 x 21.6	131 144	131 144			23.4	118.3	1 578.5	59	"	213
" "	8	0	0	"	"	"	49.6	14.1 and 21.2 x 25.6	125 620	125 620		57 882	23.5	117.9	1 578.7	60.3	Wagon	200
" "	8	0	0	"	"	"	59	13.5 and 21.2 x 25.5	125 180	125 180			25.5	112.6	1 489	56.2	Straight	213
Paris and Orleans	6	0	2	"	"	Single Expansion	59	21.2 x 25.5	115 829	94 928	20 900		23.8	112.3	1 549	56.2	Wagon	142
Eastern R. R. of France	6	2	0	"	Outside	"	60.6	19.4 x 24	115 584	87 584	28 000		18.7	126.9	1 751.7	59	Straight	156
" "	8	0	0	Without	"	"	61.4	18.1 x 23.6	122 595	122 595			19.6	95.7	1 092 4	51.1	"	142
Northern R. R.	6	0	2	"	Inside	"	61.4	18.4 x 24	124 544	94 752	29 792		19.8	95.7	1 092.1	51.2	"	142
" "	6	2	0	With	Out and Inside	Compound	64.9	17 & 19.7 x 19 7 & 25.6	106 776	90 944	15 232		22.5	100.1	1 124.8	52.5	"	199
" "	6	2	0	"	"	3-Cylinder Compound	64.9	19.7 and 17 x 27.6	104 000	89 000	15 000		22.5	100.1	1 124.8	53	"	199
" "	8	0	0	"	Outside	4 Cylinder Compound	51.2	25.7 and 14.8 x 26.6	113 987				22.4			60	"	142
" "	6	2	0	"	"	3-Cylinder Compound	64.9	17.7 & 20 x 20 & 28	106 176	90 944	15 232		22.6	100	1 124.4	52 9	"	199
Western R. R. "	6	2	0	"	Out and Inside	"	64.9	17 & 19.6 x 19.6 & 27.5	104 240	89 320	14 960		22 5	100	1 124.4	55.1	"	198.8
French State	6	0	0	Without	Inside	Single Expansion	60.6	17.2 x 24	92 960	92 960			13.7	81.8	988.8	48	"	142
Southern of France	6	0	0	With	Outside	2-Cylinder Compound	59.4	17.8 and 24 x 24	76 384	76 384			14.5	80.7	1 000.6	49.2	"	128
" "	8	0	0	"	"	Single Expansion	47.6	20.6 x 24.4	120 960	120 960			20.4	114	1 904.5	60.5	"	128
Belgian State	4	2	2	"	Inside	Woolf Compound	51.2	15.4 and 26 4 x 26	116 480	116 480			22.4	90	1 278	59	"	142
" "	6	2	0	"	"	Single Expansion	83	20 x 24					53.75	138	1 237		Belpaire	150
" "	6	2	2	Without	"	"	67	19.5 x 24								56	Straight	
" "	4	2	0	With	"	"	70.8	17.7 x 23.6	132 160					118	1 025	51	"	133
" "	4	2	0	"	"	"	79	18.11 x 24	94 080				36.6	129.2	1 053.8		"	142
" "	4	2	0	"	"	"	70.8	17 x 24	91 400	64 300	27 100		33	126	1 179	51	"	135
" "	6	2	0	"	"	"	67	18.4 x 24.4	94 080				36.6	130.2	1 053.4	51.2	Wagon	150
" "	4	2	2	"	"	"	82.7	19.7 x 23.6	117 000	90 100	26 900		61.8	161.4	1 412.5	55	Belpaire	150
Prussian "	4	2	0	"	Outside	"	68.1	19.7 x 23.6	108 400	57 750	50 650		50.7	134.6	1 207.4	51.2	"	150
" "	4	4	0	"	Inside	"	77	15.7 x 22	79 990	53 984	26 006		20.1	73.2	1 037.6	49.2	Straight	205.8
Belgian "	6	2	0	"	Inside	"	66.9	16.9 x 23.6	110 000			79 000	10.76				Lentz stayless	142
" "	6	0	0	"	"	"	51.2	20 x 24	144 464	91 616	52 848		62.4	151.7	1 435.4	55.1	Straight	142
" Central	8	0	0	Without	Outside	"	48	20 x 24	100 800	100 800			55.4	121.6	1 177.1	55.1	"	142
" State	6	0	0	"	"	"	47.2	19.4 x 24	117 376	117 376			24.7	90.3	1 523.6	59	"	156
" "	6	0	0	With	Inside	"	47.2	14 x 20	68 768	68 768			22.2	73.1	497.1	42.3	"	150
" "	6	0	0	"	Outside	"	47.2	19.7 x 23.6	93 200	93 200			55.4	122	1 177	55.1	Belpaire	150
Prussian State	6	0	0	"	"	"	52.3	17.7 x 24.8	84 700	84 700		62 700	16.4	77.4	1 259	55	Straight	174
Med. R. R of Italy	6	4	0	"	"	Von Borries Compound	52.4	17.8 and 25.6 x 24.8	78 800	78 800		52 400	16.5			53	"	150
So. " "	4	4	0	"	"	Single Expansion	66	18.5 x 24.5				57 000	24	114	1 600	60	Belpaire	
Italian Med	4	4	0	"	"	"	75.6	17.9 x 23.6	87 000	56 000	31 000	49 800				51.2	Straight	150
" "	4	4	0	"	"	"	71.5	17 x 22		58 240			23	94	930	50	Wagon	150
" Railway	4	4	0	"	"	"	83	18 x 24.5	93 800	59 000	34 800	57 000	25	107.5	1 086.7	52	Straight	142
" Med	4	4	0	"	"	"	75.6	14.2 x 24	94 080	58 240	35 840		21.5	88.2	908.9	52.3	"	142
Hungarian State	4	4	0	"	"	"	75.6	18 x 24.8	111 656	66 080	45 576		24.7	107.6	1 086.7	51.6	"	150
" "	4	4	0	"	"	"	67.5	16.9 x 25.6	92 512	56 896	35 616	70 560	21.5	92.5	1 200			190
" "	4	4	0	"	"	Woolf Compound	78.8	14.5 and 21.7 x 25.6									Straight	
" "	4	4	0	"	"	4-Cylinder Compound	77	14.6 and 21.6 x 25.6	119 900	61 500	58 400	89 286	32	129.2	1 321.4	51.2	"	190
Hanover "	4	2	0	"	"	"	72	14.1 and 21.6 x 25.6	108 800	55 800	53 000	81 000	32	140	1 452	51	"	150
St. Petersburg and Warsaw	4	4	0	"	"	Von Borries Compound	73.2	16.5 and 23.6 x 22.8	83 776	57 344	26 432		18.7	78.5	969.3	51	"	170
Jura Simplon	4	4	0	"	"	2-Cylinder Compound	78	18.1 and 26.4 x 25.6	101 200	52 000	49 200	68 000	26.5	134.6	1 437.4	54.8	"	165
Indian State	6	4	0	"	"	"	72.1	17.7 and 26.4 x 25.6	105 950	63 600	42 350	66 750	26.4	97.4	1 286	52.3	"	170
" "	4	2	0	"	"	Single Expansion	51	18 x 26	102 816	78 064	24 752	60 704	22	114.3	1 119		"	160
" "	4	4	0	"	Inside	"	79	17.5 x 24									"	160
					Outside													

TABLE A3.

GIVING DIMENSIONS OF LOCOMOTIVES IN OTHER COUNTRIES.

or	Diameter of driving wheels. Inches.	Size of cylinders. Inches.	Total weight of engine. Pounds.	Weight on driving wheels. Pounds.	Weight on truck wheels. Pounds.	Weight of tender, loaded. Pounds.	Area of grate. Square feet.	Firebox heating surface. Square feet.	Tube heating surface. Square feet.	Diameter of boiler. Inches.	Boiler, wagon top, Belpaire or straight.	Steam pressure. Pounds per square inch.	Length of tubes. Feet and Inches.	Diameter of tubes. Inches.	Description of service for which engine is built.	Capacity of water tank. Gallons.	Capacity of coal tank. Pounds.	Ratio of cylinder power to weight available for adhesion.
													Feet. Inches.					
...	78½	17 x 23.5	.....	50 000	.....	.....	.....	76	1 156	47	Straight	127	12 7	.....	Passenger	.....	.....	0.292
...	60.6	16.9 x 23.6	83 000	83 000	.....	.....	14.7	81.8	983.2	48	"	142	10 6	1.77	"	880	2 500	0.304
...	80.6	18 x 26	106 773	65 333	41 400	.....	19	.....	.....	49	Wagon.....	155	13 8½	2	"	.....	.....	0.392
...	82.5	17 x 24	.....	58 000	.....	.....	25	98	1 241	49	Straight	140	13 5	.....	"	.....	.....	0.318
...	80 3	17.2 x 24	86 688	60 032	26 656	.....	17.6	101.3	1 0-6.7	48.4	"	142	10 5	1.8	"	.....	.....	0 328
...	79.5	17.6 x 26	96 544	60 480	36 064	.....	17.6	95.7	1 197.5	48	"	170	16 3	1.8	"	.....	.....	0.447
nd..	78.7	19.7 and 12.2 x 24.4	117 947	.....	.....	.....	25.2	.....	.....	49.7	"	213	.....	.....	"	.....	.....	
...	82.5	19.5 x 25.5	.....	60 000	.....	.....	22	96	1 447	.....	"	140	.....	.....	"	346	8 800	0.430
nd..	78.7	12.4 and 20 x 24.8	118 840	66 304	52 536	.....	25.2	124.7	1 059.9	49.6	"	213	13 3	1.8	"	.....	.....	0.307
nd..	77.6	13.4 and 21.2 x 24.4	107 520	67 200	40 320	.....	25	.....	.....	.....	Wagon	215	10 0	.....	"	.....	.....	0.710
..	78.7	12.2 and 19.6 x 24.4	117 700	65 120	52 580	80 520	25.2	125	1 160.6	50.7	"	180	13 3	1.79	"	4 253	6 600	0.517
..	78.7	19.6 x 24.4	111 100	62 810	48 290	.....	24.1	112.9	1 422.5	50.7	"	136.2	16 3	1.96	"	.....	.....	0 457
....	80	17 x 25.5	.....	56 320	.....	.....	16.3	112	1 532	.....	Straight	127	.....	.....	"	.....	.....	0.311
....	84.6	18 x 28	122 528	70 336	52 192	.....	23.3	152.8	1 326.7	49.2	"	185	17 3	1.5	"	.....	.....	0.442
....	78.7	17.7 x 27.5	120 340	69 080	51 260	74 030	23.1	152.6	1 326.6	49.2	Wagon	184.6	17 0	1.88	"	3 830	6 160	0.459
....	55	18.9 x 23.6	113 300	86 020	27 280	45 672	18.7	126.9	6 411.4	50	Straight	156.2	14 7	1.88	"	1 585	8 800	0.437
....	68.5	15 x 22	67 000	46 050	20 950	.....	9.47	51.67	726.7	.....	"	.....	.....	.....	"	517	1 100	
....	83 8	18.9 x 23.6	86 400	53 800	32 600	.....	.....	118.4	1 044.1	49.2	"	.....	.....	1.77	"	.....	.....	
nd..	84	18.4 and 13.2 x 24.4	84 672	61 724	22 948	.....	24.4	102.2	1 005	48	"	156	11 8	1.8	"	.....	.....	0.390
....	83.8	19.4 x 24	96 768	60 256	36 512	.....	21.9	148.5	1 043.7	49.2	"	170	12 6	1.8	"	.....	.....	0 477
nd..	83.2	13.4 and 20.9 x 25.5	105 350	67 220	38 130	74 050	21.9	146.7	1 054.8	49.8	"	190	12 8	1.77	"	3 900	8 800	0.594
..	83	13.5 and 21 x 25	105 280	67 200	38 080	.....	21.9	116.9	1 065.2	49.5	"	182	12 9	1.75	"	.....	.....	0.565
..	83.2	13.4 and 20.9 x 25.2	105 380	67 240	38 140	.....	22	117	1 094.5	49.6	"	199	12 9.5	1.77	"	.....	.....	0.614
..	82.6	18.1 and 13 x 24	74 404	.....	.....	.....	24.4	.....	.....	52.2	"	156.4	.....	.....	"	.....	.....	
....	78.7	17.6 x 24	95 872	67 200	28 672	.....	18.4	104.4	1 098.6	50.4	"	142	11 5	1.5	"	.....	.....	0.313
....	82.2	19.7 x 26	122 950	72 150	50 800	.....	26	170.7	1 768.5	31.5 & 47.5	Double barrel.	.....	14 11	1.5	"	.....	.....	
....	80.3	16.9 x 23.6	85 250	58 960	26 290	.....	17.6	103.3	1 086.7	51.8	Straight	142	10 6	1.77	"	.....	.....	0.252
....	80.3	18.1 x 25.9	105 160	64 460	40 700	.....	19	107.6	4 913.3	52.4	"	156.2	13 8	1.92	"	.....	.....	0.402
....	60.5	17 x 23.5	69 440	.....	.....	.....	17	75	1 035	.....	"	143	11 8	1.75	Freight ..	.....	2 240	
nd..	59	21.3 and 13.4 x 25.6	125 444	.....	.....	.....	25.5	.....	.....	55.1	"	213	.....	.....	"	.....	.....	
..	49.5	21.5 and 14.2 x 25.6	125 883	.....	.....	.....	23.5	.....	.....	59	"	213	.....	.....	"	.....	.....	
..	49.6	14.4 x 21.6	131 144	131 144	.....	.....	23.4	118.3	1 578.5	59	"	213	13 7	1.8	" ..	.....	.....	0.621
..	49.6	14.1 and 21.2 x 25.6	125 620	125 620	.....	57 882	23.5	117.9	1 578.7	60.3	Wagon	200	13 7	1.8	" ..	2 113	11 000	0.589
..	59	13.5 and 21.2 x 25.5	125 180	125 180	.....	.....	25.5	112.6	1 489	56.2	Straight	213	14 2	1.77	"	.....	.....	0.519
....	59	21.2 x 25.5	115 829	94 928	20 900	.....	23.8	112.3	1 549	56.2	Wagon	142	16 6	1.96	"	.....	.....	0.466
....	60.6	19.4 x 24	115 584	87 584	28 000	.....	18.7	126.9	1 751.7	59	Straight	156	14 9	1.5	"	.....	.....	0.417
....	61.4	18.1 x 23.6	122 595	122 595	.....	.....	19.6	95.7	1 092 4	51.1	"	142	13 5	1.92	"	1 157	6 619	0.226
....	61.4	18.4 x 24	124 544	94 752	29 792	.....	19.8	95.7	1 092.1	51.2	"	142	13 5	1.5	" ..	1 376.4	6 000	0.311
....	64.9	17 & 19.7 x 19 7 & 25.6	106 776	90 944	15 232	.....	22.5	100.1	1 124.8	52.5	"	199	13 1	1.77	"	.....	.....	0.528
nd..	64.9	19.7 and 17 x 27.6	104 000	89 000	15 000	.....	22.5	100.1	1 124.8	53	"	199	13 1	1.77	"	.....	.....	0.287
und..	51.2	25.7 and 14.8 x 26.6	113 987	.....	.....	.....	22.4	.....	.....	60	"	142	.....	.....	"	.....	.....	
und..	64.9	17.7 & 20 x 20 & 28	106 176	90 944	15 232	.....	22.6	100	1 124.4	52 9	"	199	13 1	1.8	"	.....	.....	0.296
..	64.9	17 & 19.6 x 19.6 & 27.5	104 240	89 320	14 960	.....	22.5	100	1 124.4	55.1	"	198.8	13 1	1.77	"	.....	.....	0.289
....	60.6	17.2 x 24	92 960	92 960	.....	.....	13.7	81.8	988.8	48	"	142	11 4	1.8	" ..	1 058	4 413	0.281
und..	59.4	17.8 and 24 x 24	76 384	76 384	.....	.....	14.5	89.7	1 000.6	49.2	"	128	14 1	1.8	"	.....	.....	0.204
.....	47.6	20.6 x 24.4	120 960	120 960	.....	.....	20.4	114	1 904.5	60.5	"	128	16 1	2.1	"	.....	.....	0.262
.....	51.2	15.4 and 26 4 x 26	116 480	116 480	.....	.....	22.4	99	1 278	59	"	142	13 5	2	"	.....	.....	0.677
.....	83	20 x 24	.....	.....	.....	.....	53.75	138	1 237	.....	Belpaire	150	.....	1.6	Passenger	.....	.....	
.....	67	19.5 x 24	.....	.....	.....	.....	.....	.....	.....	56	Straight	.....	13 2	.....	"	.....	.....	
.....	67	17.7 x 23.6	132 160	.....	.....	.....	.....	118	1 025	51	"	133	11 6½	1.77	"	2 200	3 920	
.....	70.8	18.11 x 24	94 080	.....	.....	.....	36.6	129.2	1 053.8	.....	"	142	.....	.....	"	.....	.....	
.....	79	17 x 24	91 400	64 300	27 100	.....	35	126	1 179	51	"	135	11 6	1.77	"	.....	.....	0.309
.....	70.8	18.4 x 24.4	94 080	.....	.....	.....	36.6	130.2	1 053.4	51.2	Wagon	150	11 6	1.8	"	.....	.....	
.....	67	19.7 x 23.6	117 000	90 100	26 900	.....	61.8	161.4	1 412.5	55	Belpaire	150	13 3	1.97	"	.....	.....	0.357
.....	82.7	19.7 x 23.6	108 400	57 750	50 650	.....	50.7	134.6	1 207.4	51.2	"	150	12 7	1.77	"	.....	.....	0.451
.....	68.1	15.7 x 22	79 990	53 984	26 006	.....	20.1	73.2	1 037.6	49.2	Straight	205.8	12 1	1.8	"	2 773	8 800	0.347
.....	77	16.9 x 23.6	110 000	.....	.....	79 000	10.76	.....	.....	.....	Lentz stayless	142	.....	1.8	"	.....	.....	
.....	66.9	20 x 24	144 404	91 616	52 848	.....	62.4	151.7	1 435.4	55.1	Straight	142	13 3	2	Freight ..	.....	.....	0.349
.....	51.2	20 x 24	100 800	100 800	.....	.....	55.4	121.6	1 177.1	55.1	"	142	11 6	1.8	" ..	.....	.....	0.416
.....	48	19.4 x 24	117 376	117 376	.....	.....	24.7	90.3	1 523.6	59	"	156	11 5	2	" ..	.....	.....	0.357
.....	47.2	14 x 20	68 768	68 768	.....	.....	22.2	73.1	497.1	42.3	"	150	8 4	1.8	"	.....	.....	0.296
.....	47.2	19.7 x 23.6	95 200	95 200	.....	.....	55.4	122	1 177	55.1	Belpaire	150	11 6	1.77	"	.....	.....	0.480
.....	52.3	17.7 x 24.8	84 700	84 700	.....	62 700	16.4	77.4	1 259	55	Straight	174	14 3	2	" ..	.....	.....	0.413
pound.	52.4	17.8 and 25.6 x 24.8	78 800	78 800	.....	52 400	16.5	.....	.....	53	"	150	14 7	2	" ..	2 300	8 000	0.533
.....	66	18.5 x 24.5	.....	.....	.....	57 000	24	114	1 600	60	Belpaire	15 0	2	Passenger	2 200	7 000		
.....	75.6	17.9 x 23.6	87 000	56 000	31 000	49 800	.....	.....	.....	51.2	Straight . ..	150	11 9	1.97	"	4 933	8 000	
.....	71.5	17 x 22	.....	58 240	.....	.....	23	94	930	50	Wagon.....	150	11 6	2	"	875	.....	0.359
.....	83	18 x 24.5	93 800	59 000	34 800	57 000	25	107.5	1 086.7	52	Straight	142	.....	1.75	"	2 200	7 000	0.381
.....	75.6	14.2 x 24	94 080	58 240	35 840	.....	21.5	88.2	908.9	52.3	"	142	11 9	2	"	.....	.....	0.245
.....	75.6	18 x 24.8	111 636	66 080	45 576	.....	24.7	107.6	1 086.7	51.6	"	150	12 5	2	"	.....	.....	0.358
.....	67.5	16.9 x 25.6	92 512	56 896	35 616	70 560	21.5	92.5	1 200	.....	"	190	13 0	1.77	"	.....	.....	0.447
.....	78.8	14.5 and 21.7 x 25.6	.....	.....	.....	.....	.....	.....	.....	.....	Straight	.....	.....	.....	"	.....	.....	
pound..	77	14.6 and 21.6 x 25.6	119 900	61 500	58 400	89 286	32	129.2	1 321.4	51.2	"	190	13 1	2	"	3 000	16 000	
..	72	14.1 and 21.6 x 25.6	108 800	55 800	53 000	81 000	32	130	1 452	51	"	.....	13 1	2	"	4 488	8 000	0 887
pound.	73.2	16.5 and 23.6 x 22.8	83 776	57 344	26 432	.....	18.7	78.5	969.3	51	"	170	11 2½	2	"	.....	.....	0.405
ound ..	78	18.1 and 26.4 x 25.6	101 200	52 000	49 200	68 000	26.5	134.6	1 437.4	54.8	"	165	13 1	2	"	3 680	4 000	0.560
"	72.1	17.7 and 26.4 x 25.6	105 950	63 600	42 350	66 750	26.4	97.4	1 286	52.3	"	170	12 5	1.75	"	3 640	9 000	0.518
.....	51	18 x 26	102 816	78 064	24 752	60 704	22	114.3	1 119	.....	"	160	.....	.....	"	2 500	12 180	0.531
.....	79	17.5 x 24	80 640	56 000	24 640	53 760	19.5	100.4	1 010.2	.....	"	160	.....	.....	"	2 000	16 000	0.417
.....	66.5	17 x 24	82 208	53 760	28 448	62 328	17.1	87	989.5	.....	"	160	.....	.....	"	2 000	16 000	0.487
.....	60	18 x 24	76 160	76 160	.....	53 760	20	89.9	1 004	.....	Wagon.....	160	.....	.....	"	1 500	16 000	0.427
.....			69 440	54 208	15 232	53 760	19.6	85.3	872.8	.....	Straight	160	.....	.....	"	2 000	14 000	0.487
.....											"	160	.....	.....	"	800	2 500	0.353

" "	4	4	0	"	"	"	83 8	18.9 x 23.6	86 400	83 800	32 000			118.4	1 044.1	49.2	"						
" "	4	2	0	"	Inside	4-Cylinder Compound	84	18.4 and 13.2 x 24.4	84 672	61 724	22 918		24.4	102.2	1 003	48	"		156	11	8		
" "	4	4	0	"	"	Single Expansion	83.8	19.4 x 24	96 768	60 256	36 512		21.9	148.5	1 043.7	49.2	"		170	12	6		
" "	4	4	0	"	Outside	4-Cylinder Compound	83.2	13.4 and 20.9 x 25.5	105 350	67 220	38 130	74 050	21.9	146.7	1 054.8	49.8	"		190	12	8		
" "	4	4	0	"	"	"	83	13.5 and 21 x 25	105 280	67 200	38 080		21.9	116.9	1 065.2	49.5	"		182	12	9		
" "	4	4	0	"	"	"	83.2	13.4 and 20.9 x 25.2	105 380	67 240	38 140		22	117	1 094.5	49.6	"		199	12	9.5		
" "	4	2	0	"	Out and Ins.de	"	82.6	18.1 and 13 x 24	74 401				24.4			52.2	"		156.4				
Southern R. R. "	4	2	0	"	Outside	Single Expansion	78.7	17.6 x 24	95 872	67 201	28 672		18.4	104.4	1 098.6	50.4	"		142	11	5		
Eastern R. R. "	4	4	0	"	"	"	82.2	19.7 x 26	122 950	72 150	50 800		26	170.7	1 768.5	31.5 & 47.5	Double barrel			14	11		
" "	4	2	0	"	Inside	"	80.3	16.9 x 23.6	85 250	58 960	26 290		17.6	103.3	1 086.7	51.8	Straight		142	10	6		
" "	4	4	0	"	"	"	80.3	18.1 x 25.9	105 150	64 460	40 700		19	107.6	4 913.3	52.4	"		156.2	13	8		
Paris and St. Germain	6	0	0	"	"	"	60.5	17 x 23.5	69 440				17	75	1 035				143	11	8		
Paris, Lyons and Med	8	0	0	"	Out and Inside	4-Cylinder Compound	59	21.3 and 13.4 x 25.6	125 444				25.5			55.1	"		213				
" "	8	0	0	"	"	"	49.5	21.5 and 14.2 x 25.6	125 883				23.5			59	"		213				
" "	8	0	0	"	"	"	49.6	14.4 x 21.6	131 144	131 144			23.4	118.3	1 578.5	59	"		213	13	7		
" "	8	0	0	"	"	"	49.6	14.1 and 21.2 x 25.6	125 620	125 620		57 882	23.5	117.9	1 578.7	60.3	Wagon		200	13	7		
" "	8	0	0	"	"	"	59	13.5 and 21.2 x 25.5	125 180	125 180			25.5	112.6	1 489	56.2	Straight		213	14	2		
" "	6	0	2	"	"	Single Expansion	59	21.2 x 25.5	115 829	92 928	20 900		23.8	112.3	1 549	56.2	Wagon		142	16	6		
Paris and Orleans	6	2	0	"	Outside	"	60.6	19.4 x 24	115 584	87 584	28 000		18.7	126.9	1 751.7	59	Straight		156	14	9		
Eastern R. R. of France	8	0	0	Without	"	"	61.4	18.1 x 23.6	122 595	122 595			19.6	93.7	1 092.4	51.1	"		142	13	5		
" "	6	0	2	"	Inside	"	61.4	18.4 x 24	124 544	94 752	29 792		19.8	93.7	1 092.1	51.2	"		142	13	5		
Northern R. R. "	6	2	0	With	Out and Inside	Compound	64.9	17 & 19.7 x 19 7 & 25.6	106 776	90 944	15 232		22.5	100.1	1 124.8	52.5	"		199	13	1		
" "	6	2	0	"	"	3-Cylinder Compound	64.9	19.7 and 17 x 27.6	104 000	89 000	15 000		22.5	100.1	1 124.8	53	"		199	13	1		
" "	8	0	0	"	Outside	4 Cylinder Compound	51.2	25.7 and 14.8 x 26.6	113 987				22.4			60	"		142				
" "	6	2	0	"	"	3-Cylinder Compound	64.9	17.7 & 20 x 20 & 28	106 176	90 944	15 232		22 6	100	1 124.4	52 9	"		199	13	1		
" "	6	2	0	"	Out and Inside	"	64.9	17 & 19.6 x 19.6 & 27.5	104 240	89 320	14 960		22 5	100	1 124.4	55.1	"		198.8	13	1		
Western R. R. "	6	0	0	Without	Inside	Single Expansion	60.6	17.2 x 24	92 960	92 960			13.7	81.8	988.8	48	"		142	11	4		
French State	6	0	0	With	Outside	2-Cylinder Compound	59.4	17.8 and 24 x 24	76 384	76 384			14.5	80.7	1 009.6	49.2	"		128	14	1		
Southern of France	8	0	0	"	"	Single Expansion	47.6	20.6 x 24.4	120 960	120 960			20.4	114	1 904.5	60.5	"		128	16	1		
" "	8	0	0	"	"	Woolf Compound	51.2	15.4 and 26 4 x 26	116 480	116 480			22.4	99	1 278	59	"		142	13	5		
Belgian State	4	2	2	"	Inside	Single Expansion	83	20 x 24					53.75	138	1 237		Belpaire		150				
" "	6	2	0	"	"	"	67	19.5 x 24								56	Straight			13	2		
" "	6	2	2	Without	"	"	67	17.7 x 23.6	132 160					118	1 025	51	"		133	11	6½		
" "	4	2	0	With	"	"	70.8	18.11 x 24	94 080				36.6	129.2	1 053.8				142				
" "	4	2	0	"	"	"	79	17 x 24	91 400	64 300	27 100		35	126	1 179	51	"		135	11	6		
" "	4	2	0	"	"	"	70.8	18.4 x 24.4	94 080				36.6	130.2	1 053.4	51.2	Wagon		150	11	6		
" "	6	2	0	"	"	"	67	19.7 x 23.6	117 000	90 100	26 900		61.8	161.4	1 412.5	55	Belpaire		150	13	3		
" "	4	2	2	"	"	"	82.7	19.7 x 23.6	108 400	57 750	50 650		50.7	134.6	1 207.4	51.2	"		150	12	7		
Prussian "	4	2	0	"	Outside	"	68.1	15.7 x 22	79 990	53 984	26 006		20.1	73.2	1 037.6	49.2	Straight		205.8	12	1		
" "	4	4	0	"	"	"	77	16.9 x 23.6	110 000			79 000	10.76				Lentz stayless		142				
Belgian "	6	2	0	"	Inside	"	66.9	20 x 24	144 464	91 616	52 848		62.4	151.7	1 435.4	55.1	Straight		142	13	3		
" "	6	0	0	"	"	"	51.2	20 x 24	100 800	100 800			55.4	121.6	1 177.1	55.1	"		142	11	6		
" Central	8	0	0	Without	Outside	"	43	19.4 x 24	117 376	117 376			24.7	90.3	1 523.6	59	"		156	11	5		
" State	6	0	0	"	"	"	47.2	14 x 20	68 768	68 768			22.2	73.1	497.1	42.3	"		150	8	4		
" "	6	0	0	With	Inside	"	47.2	19.7 x 23.6	95 200	95 200			55.4	122	1 177	55.1	Belpaire		150	11	6		
" "	6	0	0	"	Outside	"	52.3	17.7 x 24.8	84 700	84 700		62 700	16.4	77.4	1 259	55	Straight		174	14	3		
Prussian State	6	0	0	"	"	Von Borries Compound	52.4	17.8 and 25.6 x 24.8	78 800	78 800		52 400	16.5			53	"		150	14	7		
Med. R. R of Italy	6	4	0	"	"	Single Expansion	66	18.5 x 24.5				57 000	24	114	1 600	60	Belpaire			15	0		
So. " "	4	4	0	"	"	"	75.6	17.9 x 23.6	87 000	56 000	31 000	49 800				51.2	Straight		150	11	9		
Italian Med	4	4	0	"	"	"	71.5	17 x 22		58 240			23	94	930	50	Wagon		150	11	6		
" "	4	4	0	"	"	"	83	18 x 24.5	93 800	59 000	34 800	57 000	25	107.5	1 086.7	52	Straight		142				
" Railway	4	4	0	"	"	"	75.6	14.2 x 24	94 080	58 240	35 840		21.5	88.2	938.9	52.3	"		142	11	9		
" Med	4	4	0	"	"	"	75.6	18 x 24.8	111 656	66 080	45 576		24.7	107.6	1 086.7	51.6	"		150	12	5		
Hungarian State	4	4	0	"	"	"	67.5	16.9 x 25.6	92 512	56 896	35 616	70 560	21.5	92.5	1 200				190	13	0		
" "	4	4	0	"	"	Woolf Compound	78.8	14.5 and 21.7 x 25.6									Straight						
" "	4	4	0	"	"	4-Cylinder Compound	77	14.6 and 21.6 x 25.6	119 900	61 500	58 400	89 286	32	129.2	1 321.4	51.2	"		190	13	1		
" "	4	4	0	"	"	"	72	14.1 and 21.6 x 25.6	108 800	55 800	53 000	81 000	33	130	1 452	51	"			13	1		
Hanover "	4	2	0	"	"	Von Borries Compound	73.2	16.5 and 23.6 x 22.8	83 776	57 344	26 432		18.7	78.5	969.3	51	"		170	11	2½		
St. Petersburg and Warsaw	4	4	0	"	"	2-Cylinder Compound	78	18.1 and 26.4 x 25.6	101 200	52 000	49 200	68 000	26.5	134.6	1 437.4	54.8	"		165	13	1		
Jura Simplon	4	4	0	"	"	"	72.1	17.7 and 26.4 x 25.6	105 950	63 600	42 350	66 750	26.4	97.4	1 286	52.3	"		170	12	5		
Indian State	6	4	0	"	"	Single Expansion	51	18 x 26	102 816	78 054	24 752	60 704	22	114.3	1 119		"		160				
" "	4	2	0	"	Inside	"	79	17.5 x 24	80 640	56 000	24 640	53 760	19.5	100.4	1 019.2		"		160				
" "	4	4	0	"	Outside	"	66.5	17 x 24	82 208	53 760	28 448	62 328	17.1	87	989.5		"		160				
" "	6	0	0	"	Inside	"	60	18 x 24	76 160	76 160		53 760	20	89.9	1 004		Wagon		160				
" "	4	0	2	"	"	"	66	17 x 24	69 440	54 208	15 232	53 760	19.6	85.3	871.8		Straight		160				
Great Indian Peninsular	4	0	2	Without	Outside	"	54	13 x 22	92 288	63 616	28 672		13	72	693		"		160				
" " "	6	0	2	"	Inside	"	54	16 x 24	110 208	90 048	20 160		15	67	793				160				
" " "	4	4	0	With	"	"	66	18 x 26	94 976	62 720	32 256	58 240	20	93.7	1 067		Straight		160				
Bengal and Nagpur	6	4	0	"	Outside	Compound	51	18 and 26 x 26	109 880	75 320	34 560	74 520	22	104	1 119		"		160				
" " "	6	4	2	Without	"	Single Expansion	51	18 x 26	129 920	83 440	46 480			104	1 119		"		160				
Oude and Rohilcunde	4	2	0	With	Outside	3-Cylinder Compound	72	12 and 24 x 24	72 500	51 500	21 000	48 000	15.4	101	911		"		160				
Jura Berne Luzerne	6	2	0	"	"	Von Borries Compound	59	18¼ and 25½ x 26	95 700				16	80.5	1 221.5		"		162				
" " "	6	2	0	"	"	" "	59.8	16.7 and 25.2 x 25.6	94 300			45 300	16.1	80.7	1 223.9		"		156				
Lanyo R. R	4	2	2	Without	"	Single Expansion	52	14 x 22	78 400				12	70	654		"						
Italian Med	8	0	0	With	"	"	48	21 x 24	118 720	118 720			23	115	1 646	59	"		135	17	0		
Indian Midland	6	2	0	"	Inside	"	54.5	17.5 x 24	107 688	91 728	15 960		19	85	949	49	"		160	10	10		
Swedish State	6	4	0	"	Outside	"	51	18 x 26					22	108	1 119	52	"		165	11	5		
" Norweg an	8	0	0	"	"	"	51	20 x 26						115	1 295	54	"			12	7		
Belgian State	6	0	0	"	Inside	"	51	19.6 x 23.5	96 320	96 320			55	121	1 170	55	"		150	11	5½		
St. Gothard	8	0	0	"	Outside	"	46	20.5 x 24	114 000	114 000			23	102	1 640	60.4	"			13	9		
Swiss No. Eastern	4	0	0	Without	"	"	54.7	12.6 x 23.6					11.9	55.5	688.4		"			9	10		
Japan Ry	6	2	0	With	"	"	48	18 x 22	80 000	72 000	8 000					37	"		150	10	9		
New So. Wales	6	2	0	"	"	"	60.5	18 x 26	96 000	79 000	17 000	72 700	17	123	1 065	55	"		150	10	10½		
" "	8	2	0	"	"	Von Borries Compound	51	13.5 and 32 x 26	137 000	123 000	14 000	72 000	21.4	158	1 802	64	"		160	13	4		
Japan Ry	4	2	2	Without	"	Single Expansion	51	14 x 20					12	70	654		"						
St. Gothard	12	0	0	"	"	Mallett Compound	43	15.5 and 22.5 x 23	188 160	188 160			23	103.2	1 597.8		"		150				
Argentine No. Eastern	6	0	0	With	"	Single Expansion	48	14.2 x 23.3	66 752	66 752			13.5	63.4	697.2	43.9	"		129	10	6		
Saxon State	8	0	0	Without	"	4-Cylinder Compound	43 2	11.8 and 18.1 x 21	112 400	112 400			14.7	58.2	871.8		"		170				
Russian R. R.	8	0	0	"	"	Single Expansion	47.3	19.7 x 25.6	124 746	124 743			19.9	98.5	1 356.3	57.9	"		150	12	2		
Uruguay Cent	4	4	0	"	"	2-Cylinder Compound	60	16 and 23 x 22					16	87	743		"						
" "	6	2	0	With	"	"	54	17½ and 25 x 24					17.5	86	930		"						
St. Gothard R. R	12	0	0	Without	"	Mallett Compound	48.5	15.7 and 32.8 x 25.2	170 000	170 000							"		180				
Indian State	8	0	0	"	Inside	Single Expansion	48	18 x 26	134 400	134 400			22		1 153.5		"		160				
" "	6	0	2	"	Outside	4-Cylinder Compound		15 & 18.9x23.6 & 15.7	113 740	86 970	26 770						"		160				
" "	6	0	0	With	"	Single Expansion	50	19 x 26	97 328	97 328		87 136	22	104	1 278.5		"		160				
Oude and Rohilcunde	8	0	0	"	Inside	"	48	16.5 x 24	66 000	66 000		56 000	16.5	101	1 007		"		150				
Mexican Ry	12	0	0	Without	Outside	"	42	16 x 22	184 000	184 000			33	180	1 332		"		165				
" Central	12	2	2	"	"	Johnstone Compound	48	13 and 28 x 24	230 000	200 000	30 000					52			180	15	9		
Royal Saxon	8	0	0	"	"	M. L. D. Compound	43.3	12 and 18 x 21	100 400	100 400			15	59	871		Straight		184.7				
Saxon State	8	0	0	"	"	Meyer Compound	44	12 and 18.4 x 21.3	114 240	114 240			14.7	59.2	870.7		"		170.6				

NOTE. Where the boiler pressure could not be determined from the description of the locomotives, as given by the builders and operators of the locomotives, it has been assumed to be 160 lbs. per square inch above the atmosphere.
For compound locomotives the figures in the last column of ratios are based on the capacity of the low-pressure cylinders only, the volume of the high-pressure being omitted. This has been done for the purpose of comparison, and because there is no single expansion and compound locomotives.

.....	83.8	19.4 x 24	96 768	60 256	36 512	.....	21.9	148.5	1 043.7	49.2	"	170	12	6	1.8	"	.....	.....	0 477
.....	83.2	13.4 and 20.9 x 25.6	105 350	67 220	38 130	74 050	21.9	146.7	1 034.8	49.8	"	190	12	8	1.77	"	3 900	8 800	0.594
..	83	13.5 and 21 x 25	105 280	67 200	38 080	.....	21.9	116.9	1 065.2	49.5	"	182	12	9	1.75	"	.....	.....	0.565
..	83.2	13.4 and 20.9 x 25.2	105 380	67 240	38 140	.....	22	117	1 094.5	49.6	"	199	12	9.5	1.77	"	.....	.....	0.614
..	82.6	18.1 and 13 x 24	74 404	.....	.....	.....	24.4	.....	.....	52.2	"	156.4	.....	.....	.....	"	.....	.....	.....
.....	78.7	17.6 x 24	95 872	67 200	28 672	.....	18.4	104.4	1 098.6	50.4	"	142	11	5	1.5	"	.....	.....	0.313
.....	82.2	19.7 x 26	122 950	72 150	50 800	.....	26	170.7	1 768.5	31.5 & 47.5	Double barrel.	.....	14	11	1.5	"	.....	.....	.....
.....	80.3	16.9 x 24.6	85 250	58 960	26 290	.....	17.6	103.3	1 086.7	51.8	Straight	142	10	6	1.77	"	.....	.....	0.252
.....	80.3	18.1 x 25.9	105 160	64 460	40 700	.....	19	107.6	4 913.3	52.4	"	156.2	13	8	1.92	"	.....	.....	0.402
.....	60.5	17 x 23.5	69 440	.....	.....	.....	17	75	1 035	.....	"	143	11	8	1.75	Freight ..	.....	2 240	.....
.....	59	21.3 and 13.4 x 25.6	125 444	.....	.....	.....	25.5	.....	.....	55.1	"	213	.....	.....	.....	"	.....	.....	.....
..	49.5	21.5 and 14.2 x 25.6	125 883	.....	.....	.....	23.5	.....	.....	59	"	213	.....	.....	.....	"	.....	.....	.....
..	49.6	14.4 x 21.6	131 144	131 144	.....	.....	23.4	118.3	1 578.5	59	"	213	13	7	1.8	"	.....	.....	0.621
..	49.6	14.1 and 21.2 x 25.6	125 620	125 620	.....	57 882	23.5	117.9	1 578.7	60.3	Wagon	200	13	7	1.8	"	2 113	11 000	0.580
..	59	13.5 and 21.2 x 25.5	125 180	125 180	.....	.....	25.5	112.6	1 489	56.2	Straight	213	14	2	1.77	"	.....	.....	0.519
.....	59	21.2 x 25.5	115 829	94 928	20 900	.....	23.8	112.3	1 549	56.2	Wagon	142	16	6	1.96	"	.....	.....	0.466
.....	60.6	19.4 x 24	113 584	87 584	28 000	.....	18.7	126.9	1 751.7	59	Straight	156	14	9	1.5	"	.....	.....	0.417
.....	61.4	18.1 x 23.6	122 595	122 595	.....	.....	19.6	95.7	1 092 4	51.1	"	142	13	5	1.92	"	1 157	6 619	0.226
.....	61.4	18.4 x 24	124 544	94 752	29 792	.....	19.8	95.7	1 092.1	51.2	"	142	13	5	1.5	"	1 376.4	6 000	0.311
.....	64.9	17 & 19.7 x 19 7 & 25.6	106 776	90 944	15 232	.....	22.5	100.1	1 124.8	52.5	"	199	13	1	1.77	"	.....	.....	0.528
.....	64.9	19.7 and 17 x 27.6	104 000	89 000	15 000	.....	22.5	100.1	1 124.8	53	"	199	13	1	1.77	"	.....	.....	0.287
.....	51.2	25.7 and 14.8 x 26.6	113 987	.....	.....	.....	22.4	.....	.....	60	"	142	.....	.....	.....	"	.....	.....	.....
.....	64.9	17.7 & 20 x 20 & 28	106 176	90 944	15 232	.....	22·6	100	1 124.4	52 9	"	199	13	1	1.8	"	.....	.....	0.296
..	64.9	17 & 19.6 x 19.6 & 27.5	104 240	89 320	14 960	.....	22 5	100	1 124.4	55.1	"	198.8	13	1	1.77	"	.....	.....	0.289
.....	60.6	17.2 x 24	92 960	92 960	.....	.....	13.7	81.8	988.8	48	"	142	11	4	1.8	"	1 058	4 443	0.281
.....	59.4	17.8 and 24 x 24	76 384	76 384	.....	.....	14.5	80.7	1 000.6	49.2	"	128	14	1	1.8	"	.....	.....	0.204
.....	47.6	20.6 x 24.4	120 960	120 960	.....	.....	20.4	114	1 904.5	60.5	"	128	16	1	2.1	"	.....	.....	0.262
.....	51.2	15.4 and 26 4 x 26	116 480	116 480	.....	.....	22.4	99	1 278	59	"	142	13	5	2	"	.....	.....	0.677
.....	83	20 x 24	.....	.....	.....	.....	53.75	138	1 237	.....	Belpaire	150	.....	.....	1.6	Passenger	.....	.....	.....
.....	67	19.5 x 24	.....	.....	.....	.....	.....	.....	.....	56	Straight	.....	13	2	.....	"	.....	.....	.....
.....	67	17.7 x 23.6	132 160	.....	.....	.....	.....	118	1 025	51	"	133	11	6½	1.77	"	2 200	3 920	.....
.....	70.8	18.11 x 24	94 080	.....	.....	.....	36.6	129.2	1 053.8	.....	"	142	.....	.....	.....	"	.....	.....	.....
.....	79	17 x 24	91 400	64 300	27 100	.....	35	126	1 179	51	"	135	11	6	1.77	"	.....	.....	0.309
.....	70.8	18.4 x 24.4	94 080	.....	.....	.....	36.6	130.2	1 053.4	51.2	Wagon	150	11	6	1.8	"	.....	.....	.....
.....	67	19.7 x 23.6	117 000	90 100	26 900	.....	61.8	161.4	1 412.5	55	Belpaire	150	13	3	1.97	"	.....	.....	0.357
.....	82.7	19.7 x 23.6	108 400	57 750	50 650	.....	50.7	134.6	1 207.4	51.2	"	150	12	7	1.77	"	.....	.....	0.451
.....	68.1	15.7 x 22	79 990	53 984	26 006	.....	20.1	73.2	1 037.6	49.2	Straight	205.8	12	1	1.8	"	2 773	8 800	0.347
.....	77	16.9 x 23.6	110 000	.....	.....	79 000	10.76	.....	.....	.....	Lentz stayless	142	.....	.....	1.8	"	.....	.....	.....
.....	66.9	20 x 24	144 464	91 616	52 848	.....	61.4	151.7	1 435.4	55.1	Straight	142	13	3	2	Freight ..	.....	.....	0.349
.....	51.2	20 x 24	100 800	100 800	.....	.....	55.4	121.6	1 177.1	55.1	"	142	11	6	1.8	" ..	.....	.....	0.416
.....	48	19.4 x 24	117 376	117 376	.....	.....	24.7	90.3	1 523.6	59	"	156	11	5	2	" ..	.....	.....	0.357
.....	47.2	14 x 20	68 768	68 768	.....	.....	22.2	73.1	497.1	42.3	"	150	8	4	1.8	" ..	.....	.....	0.296
.....	47.2	19.7 x 23.6	95 200	95 200	.....	.....	55.4	122	1 177	55.1	Belpaire	150	11	6	1.77	" ..	.....	.....	0.480
.....	52.3	17.7 x 24.8	84 700	84 700	.....	62 700	16.4	77.4	1 259	55	Straight	174	14	3	2	" ..	.....	.....	0.413
pound.	52.4	17.8 and 25.6 x 24.8	78 800	78 800	.....	52 400	16.5	.....	.....	53	"	150	14	7	2	" ..	2 300	8 000	0.533
.....	66	18.5 x 24.5	.....	.....	.....	57 000	24	114	1 600	60	Belpaire	.....	15	0	2	Passenger	2 200	7 000	.....
.....	75.6	17.9 x 23.6	87 000	56 000	31 000	49 800	.....	.....	.....	51.2	Straight . ..	150	11	9	1.97	"	4 933	8 000	.....
.....	71.5	17 x 22	.....	58 240	.....	.....	23	94	930	50	Wagon	150	11	6	2	"	875	.....	0.339
.....	83	18 x 24.5	93 800	59 000	34 800	57 000	25	107.5	1 086.7	52	Straight	142	.....	.....	1.75	"	2 200	7 000	0.381
.....	75.6	14.2 x 24	94 080	58 240	35 840	.....	21.5	88.2	938.9	52.3	"	142	11	9	2	"	.....	.....	0.245
.....	75.6	18 x 24.8	111 636	66 080	45 576	.....	24.7	107.6	1 086.7	51.6	"	150	12	5	2	"	.....	.....	0.358
.....	67.5	16.9 x 25.6	92 512	56 896	35 616	70 560	21.5	92.5	1 200	.....	.....	190	13	0	1.77	"	.....	.....	0.447
.....	78.8	14.5 and 21.7 x 25.6	.....	.....	.....	.....	.....	.....	.....	.....	Straight	.....	.....	.....	.....	"	.....	.....	.....
pound..	77	14.6 and 21.6 x 25.6	119 900	61 510	58 400	89 286	32	129.2	1 322.4	51.2	"	190	13	1	2	"	3 000	16 000	.....
..	72	14.1 and 21.6 x 25.6	108 800	55 800	53 000	81 000	33	130	1 452	51	"	.....	13	1	2	"	4 488	8 000	0 887
pound.	73.2	16.5 and 23.6 x 22.8	83 776	57 344	26 432	.....	18.7	78.5	969.3	51	"	170	11	2½	2	"	.....	.....	0.605
pound..	78	18.1 and 26.4 x 25.6	101 200	52 000	49 200	68 000	26.5	134.6	1 437.4	54.8	"	165	13	1	2	"	3 680	4 000	0.560
	72.1	17.7 and 26.4 x 25.6	105 950	63 600	42 350	66 750	26.4	97.4	1 286	52.3	"	170	12	5	1.75	"	3 640	9 000	0.518
.....	51	18 x 26	102 816	78 054	24 752	60 704	22	114.3	1 119	.....	"	160	.....	.....	.....	"	2 500	12 180	0.531
.....	79	17.5 x 24	80 640	56 000	24 640	53 760	19.5	100.4	1 010.2	.....	"	160	.....	.....	.....	"	2 000	16 000	0.417
.....	66.5	17 x 24	82 208	53 760	28 448	62 328	17.1	87	989.5	.....	"	160	.....	.....	.....	"	2 000	16 000	0.487
.....	60	18 x 24	76 160	76 160	.....	53 760	20	89.9	1 004	.....	Wagon	160	.....	.....	.....	"	1 500	16 000	0.427
.....	66	17 x 24	69 440	54 208	15 232	53 760	19.6	85.3	873.8	.....	Straight	160	.....	.....	.....	"	2 000	16 000	0.487
.....	54	15 x 22	92 288	63 616	28 672	.....	13	72	691	.....	"	160	.....	.....	.....	"	800	2 500	0.353
.....	54	16 x 24	110 208	90 048	20 160	.....	15	67	793	.....	.....	160	.....	.....	.....	"	1 250	3 920	0.317
.....	66	18 x 26	94 976	62 720	32 256	58 240	20	93.7	1 067	.....	Straight	160	.....	.....	.....	"	2 000	8 000	0.511
.....	51	18 and 26 x 26	109 880	75 320	34 560	74 520	22	104	1 119	.....	"	160	.....	.....	.....	"	2 500	22 000	0.575
.....	51	18 x 26	129 920	83 440	46 480	.....	.....	104	1 119	.....	"	160	.....	.....	.....	"	950	6 640	0.497
pound..	72	12 and 24 x 24	72 500	51 500	21 000	48 000	15.4	101	911	.....	"	160	.....	.....	.....	"	1 800	16 000	0.465
pound.	59	18½ and 25½ x 26	95 700	.....	.....	.....	16	80.5	1 221.5	.....	"	162	.....	.....	.....	"	1 500	9 240	.....
..	59.8	16.7 and 25.2 x 25.6	94 300	.....	.....	45 300	16.1	89.7	1 223.9	.....	"	156	.....	.....	.....	Freight ..	1 570	9 230	.....
.....	52	14 x 22	78 400	.....	.....	.....	12	70	651	.....	"	.....	.....	.....	.....	" ..	1 000	3 600	.....
.....	48	21 x 24	118 720	118 720	.....	.....	23	115	1 646	59	"	135	17	0	2	" ..	1 383	.....	0.393
.....	54.5	17.5 x 24	107 688	91 728	15 960	.....	19	85	949	49	"	160	10	10	2	" ..	800	6 000	0.369
.....	51	18 x 26	.....	.....	.....	.....	22	108	1 119	52	"	165	11	5	1¾	"	.....	.....	.....
.....	51	20 x 26	.....	.....	.....	.....	.....	115	1 295	54	"	.....	13	7	2	" ..	1 800	.....	.....
.....	51	19.6 x 23.5	96 320	96 320	.....	.....	55	121	1 170	55	"	150	11	5¾	1¾	"	.....	.....	0.434
.....	46	20.5 x 24	114 000	114 000	.....	.....	23	102	1 660	60.4	"	.....	13	9	1.97	"	.....	.....	.....
.....	54.7	12.6 x 23.6	.....	.....	.....	.....	11.9	53.5	688.4	.....	"	.....	9	10	1.97	" ..	708	.....	.....
.....	48	18 x 22	80 000	72 000	8 000	.....	.....	.....	.....	37	"	150	10	9	2	" ..	2 600	.....	0.485
.....	60.5	18 x 26	96 000	79 000	17 000	72 700	17	121	1 065	55	"	150	10	10¾	2	" ..	3 600	10 000	0.415
pound.	51	13.5 and 32 x 26	137 000	123 000	14 000	72 000	21.4	158	1 803	64	"	160	13	4	2½	" ..	3 600	.....	0.504
.....	51	14 x 20	.....	.....	.....	.....	12	70	651	.....	"	.....	.....	.....	.....	" ..	1 000	3 600	.....
.....	48	15.5 and 22.5 x 25	188 160	188 160	.....	.....	23	102.2	1 597.8	.....	"	150	.....	.....	.....	" ..	1 800	8 900	0.330
.....	48	14.2 x 23.3	66 752	66 752	.....	.....	13.5	63.4	697.2	43.9	"	159	10	6	1.8	"	.....	.....	0.320
and ..	43 2	11.8 and 18.1 x 21	112 400	112 400	.....	.....	14.7	58.2	871.8	.....	"	170	.....	.....	.....	" ..	1 200	4 000	0.377
.....	47.3	19.7 x 25.6	124 746	124 745	.....	.....	19.9	98.5	1 356.3	57.9	"	150	12	2	.....	"	.....	.....	0.306
mud..	60	16 and 23 x 22	.....	.....	.....	.....	16	87	743	.....	"	.....	.....	.....	.....	" ..	2 000	8 500	.....
.....	54	17½ and 25 x 24	.....	.....	.....	.....	17.5	86	930	.....	"	.....	.....	.....	.....	" ..	1 700	8 500	.....
d	48.5	15.7 and 32.8 x 25.2	170 000	170 000	.....	.....	.....	.....	.....	.....	"	180	.....	.....	.....	" ..	.....	.....	0.929
.....	48	18 x 26	134 400	134 400	.....	.....	22	.....	1 153.5	.....	"	160	.....	.....	.....	" ..	1 550	7 200	0.328
pound..	.....	15 & 18.9x23.6 & 15.7	113 740	86 970	26 770	.....	.....	.....	.....	.....	"	160	.....	.....	.....	"	.....	.....	.....
.....	50	19 x 26	97 328	97 328	.....	87 136	21	104	1 278.5	.....	"	160	.....	.....	.....	" ..	3 000	.....	0.484
.....	48	16.5 x 24	66 000	66 000	.....	56 000	16.5	101	1 007	.....	"	150	.....	.....	.....	" ..	1 700	10 400	0.485
.....	42	16 x 22	184 000	184 000	.....	.....	33	180	1 832	.....	"	165	.....	.....	.....	" ..	2 850	.....	0.188
pound..	48	13 and 28 x 24	230 000	200 000	30 000	.....	.....	.....	.....	52	.....	189	15	9	2.75	" ..	3 000	10 000	0.357
and	43.3	12 and 18 x 21	103 400	100 400	.....	.....	15	59	871	.....	Straight	184.7	.....	.....	.....	" ..	1 300	6 900	0.227
d	44	12 and 18.4 x 21.3	114 240	114 240	.....	.....	14.7	59.2	879.7	.....	"	170.6	.....	.....	.....	" ..	1 325	4 256	0.386

rs, as given by the builders and operators of the locomotives, it has been assumed to be 160 lbs. per square inch above the atmosphere.
the low-pressure cylinders only, the volume of the high-pressure being omitted. This has been done for the purpose of comparison, and because there is no accurate simple way of comparing the cylinder power of

incongruous the designs may appear in some cases, as a result of the use of the same parts for large and small engines, yet railroad men prefer that the harmony of design should suffer rather than keep in stock a larger supply of duplicate parts.

In Conclusion.—The important distinctive features of American locomotive practice are large dimensions, great hauling power, duplication of parts, steel fireboxes, bar-frames, the universal use of equalizers for all types, and cast-iron driving-wheel centers ; these are manifest advantages from an American standpoint; also, as distinctive features and of questionable advantage, are tenders with swiveling trucks, and small drivers for high speeds. A distinctive feature and a decided disadvantage is the use of heavy reciprocating parts.

The locomotives used in foreign countries are now, generally speaking, of about the same weight and power as those used here 10 years ago, and the heaviest foreign types for passenger service are about the same weight as our light eight-wheel type. There are none used elsewhere on comparatively level roads that are as powerful as our ten-wheel and mogul express engines. The average practice in various countries is given in Tables A1, A2, A3, which shows how closely some of the foreign types approach the American in general features of construction. Abroad there are many and varied types of locomotives, and abrupt changes in construction are more common than in the United States. So varied are the plans followed, and so rapidly do the changes in important details take place, that the onlooker receives the impression that a general dissatisfaction exists. Recent developments have followed American plans, both in weight and type, in a way that is complimentary, and there is some evidence that when foreign locomotive designs become more constant, and the process of selection evolves a nearly universal set of types, some of the features that are now distinctively American will find a place in the ultimate plan. One distinctive feature of the American locomotive construction that will eventually become universal is the steel firebox. The policy of hauling heavy trains, which is a distinctive feature of American locomotive practice, is so clearly advantageous that sooner or later all countries having long distances and competition between common carriers will run heavy trains and will construct ponderous locomotives to haul them.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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(Vol. XXIX.—August, 1893.)

COMPARISON OF MODERN ENGINE LOADING, WITH STANDARD SPECIFICATIONS FOR SPANS FROM 10 TO 200 FEET.

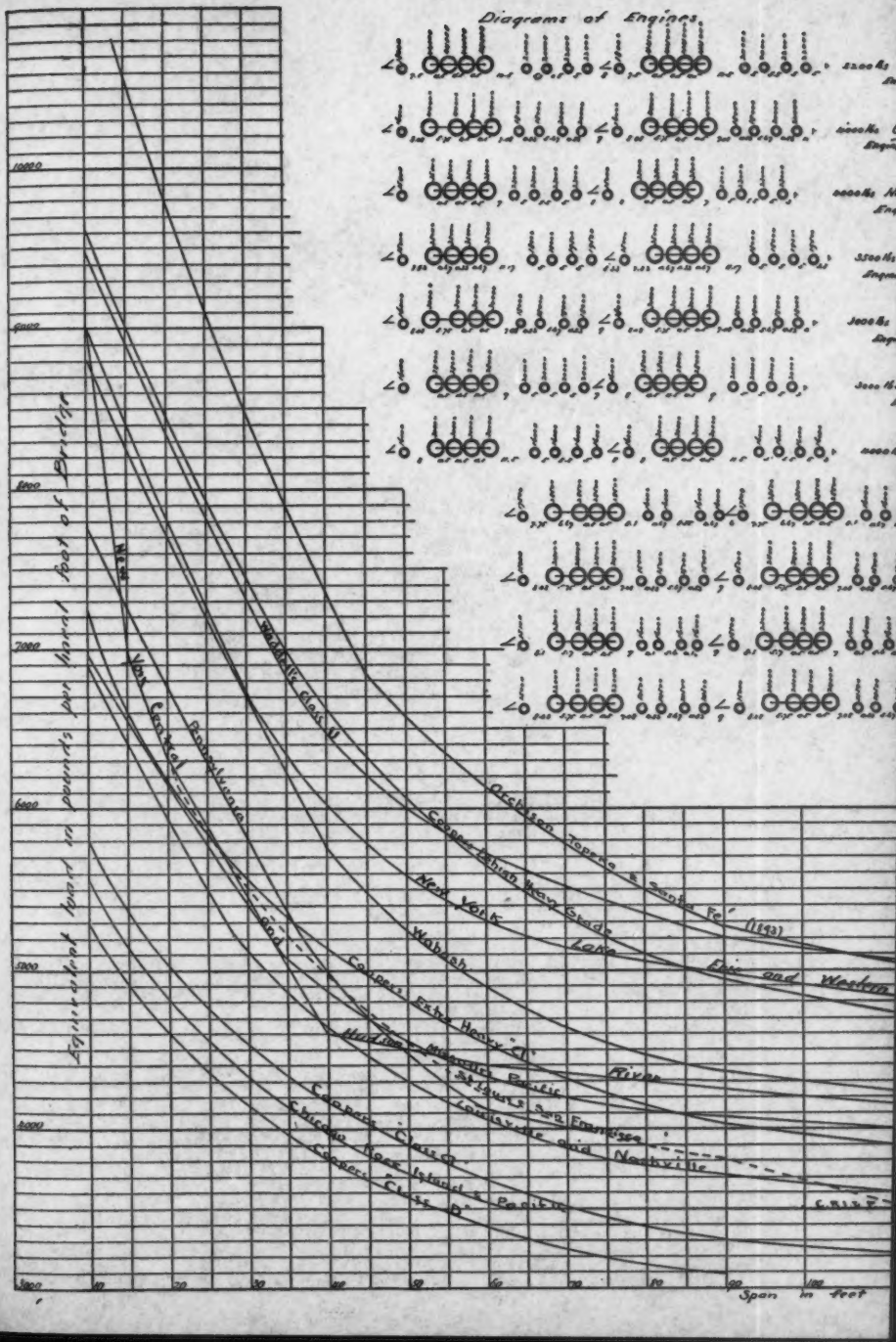
By C. D. PURDON, M. Am. Soc. C. E.

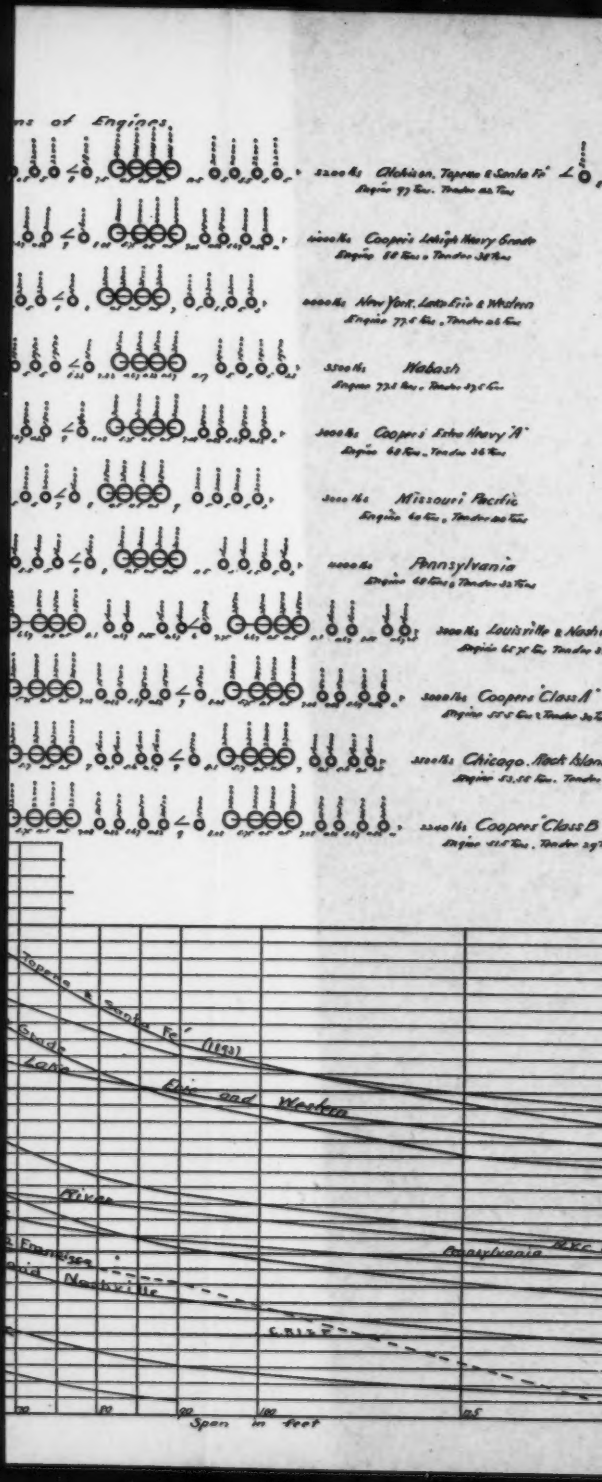
Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The World's Columbian Exposition having called attention to a number of engines of the latest designs and of much greater weight than have been used heretofore, the writer has thought it interesting to compare these engines, with regard to the effect on a bridge, with the engines specified as typical by some important roads.

One diagram (Plate I), from certain bridge specifications, shows a series of curves representing the loading from the typical engines specified. This diagram is made by calculating the bending moment

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.


Diagrams of Engines
Pressure per Sq. Inch Panel Area Sprung in Pounds
10000
9000
8000
7000
6000
5000
4000
3000
10
20
30
40
50
60
70
80
90
100
Span in Feet
Wabash
Pennsylvania
Cooper's Class D
Cooper's Class C
Cooper's Class B
Cooper's Class A
Cooper's Class E
Cooper's Class E Heavy
Cooper's Class E Heavy Goods
Atchison, Topeka & Santa Fe (1893)
Lake Erie and Western
Fixed
Louisville and Nashville
C.B.&Q.


ns of Engines.
Atchison, Topeka & Santa Fé
Cooper's Lehigh Heavy Grade
New York, Lake Erie & Western
Wabash
Cooper's Extra Heavy "A"
Missouri Pacific
Pennsylvania
Louisville & Nash
Cooper's Class A
Chicago, Rock Islan
Cooper's Class B
Topeka & Santa Fé (1893)
Grade
Lake
Erie and Western
Pikes
Peak
Tennessee
and
Nashville
Pennsylvania R.R.
C.B.I. & P.
Span in feet

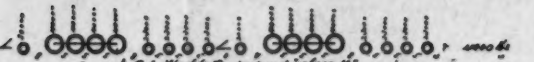


Diagram of Bridge Specifications

Showing the distributed load in pounds per lineal foot which produces the same maximum moments as the two engines described in the Specifications

Beams or Girders up to 90 ft span, from 100 to 200 ft spans, Pratt Truss with 25 ft panels

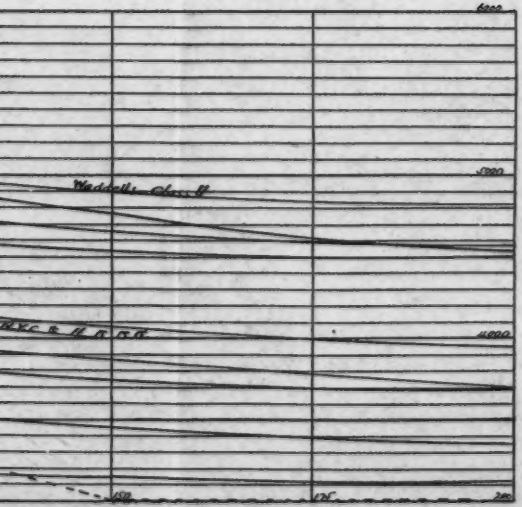
Note. The New York Central & Hudson River and the St Louis & San Francisco Rys. both specify a certain load per lineal foot instead of a typical engine

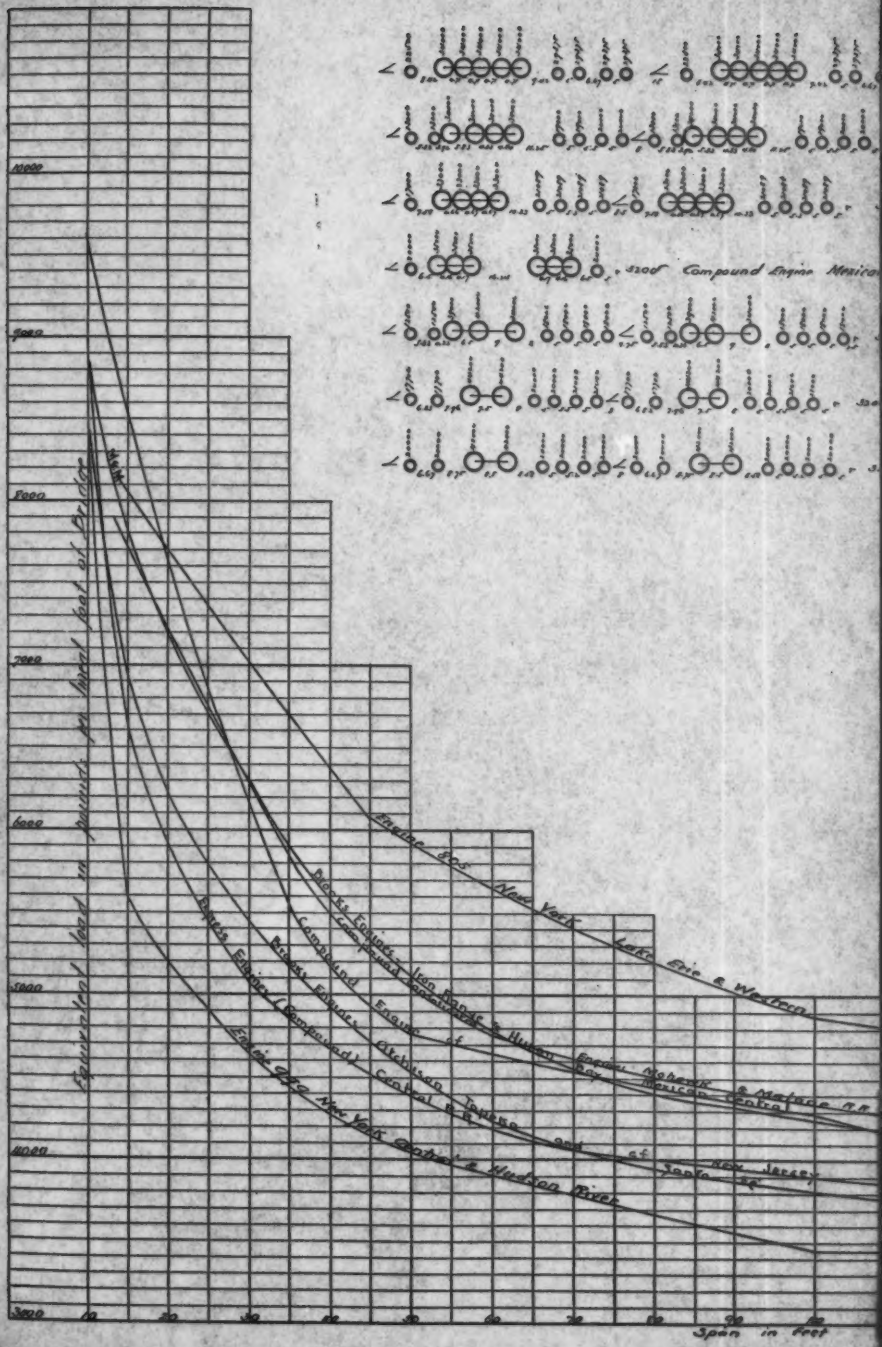
...Nashville
...under 22 Tons

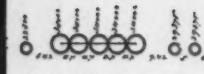
"...lass A"
...under 34 Tons

...k Island & Pacific
Tender 22 Tons

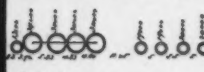
"Class B"
...der 29 Tons



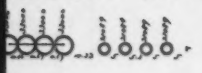

Compound Engine Mexico
Engine for New York Lake Erie & Western
Brooks Engine Van Rensselaer & Hudson
Compound Engine
Brooks Engine Lehigh Valley
Brooks Engine Delaware Lackawanna & Western
Engine Mohawk & Malone
Mexican Central
British Engine (Compound) Central R.R.
Engine for New York Central & Hudson River
Tonnage on 1 ft. Truss in Pounds per Foot
Span in Feet



4000 lbs Engine 805 New York Lake Erie & Western
Engine 96.35 Tons. Tender 58.35 Tons

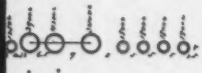


3200 Brooks Engine Iron Range & Huron Bay
Engine 81 Tons Tender 49 Tons

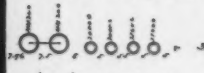


3200 Compound Engine Mohawk & Malone
Engine 74.6 Tons Tender 42.18 Tons

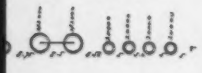
Compound Engine Mexican Central - Total weight 118 Tons



3200 Brooks Engines Atchison Topeka & Santa Fe'
Engine 70 Tons. Tender 36 Tons



3200 Compound Engine Central R. R. of New Jersey
Engine 61.9 Tons. Tender 41 Tons

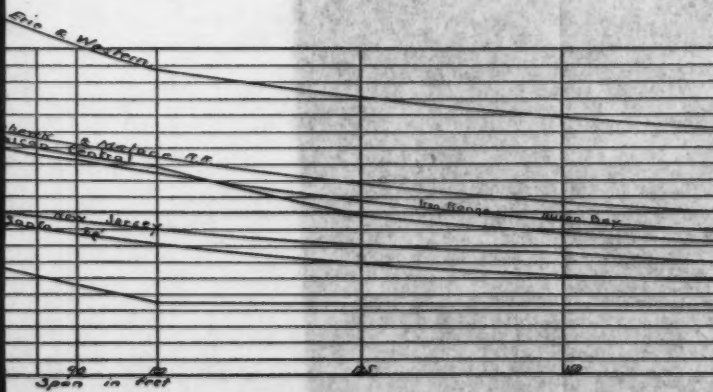


3200 Engine 999 New York Central & Hudson River
Engine 62 Tons. Tender 44 Tons

Comparative Weight of Some Modern E

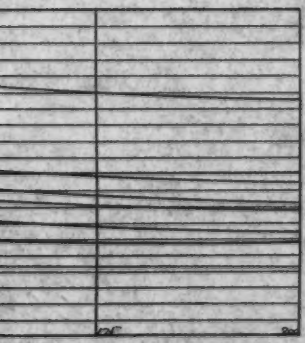
Showing the
pounds per lineal foot which
maximum moments as thro of

Beams or girders up to 90 ft span - fro
Spans with 25 ft panels



Engines

the distributed load in
hich produces the same
ro of the engines
- from 100 to 200 ft, Pratt Truss



of the engines on girders up to 90-ft. spans, beginning at 10-ft. spans and increasing by 5 ft.; and on Pratt trusses from 100-ft. to 200-ft. spans, beginning at 100 ft. and increasing by 25 ft., using panels 25 ft. long. After calculating the bending moment, the writer then found the distributed load per linear foot on the same spans, which would cause the same moments. Then plotting these loads on the diagram, he drew a curve to pass as nearly through all the points as possible. From spacing of the wheels, etc., a line representing the actual moments would be somewhat irregular; the curve gives a fair average.

The other diagram (Plate II), from some modern engines, was made precisely in the same way. The information at hand did not always give quite enough data for an accurate diagram. The distance between two engines and the distance from the last wheel to the head of the train not being given, these were assumed, as was also the following—load of 3 200 pounds per linear foot, except in the case of engine No. 805, New York, Lake Erie and Western, when 4 000 lbs. were taken. Although it is not probable that two engines like No. 805 would be coupled together in actual service, still, as nearly all bridge specifications use two engines, it is better for the purposes of comparing actual with typical engines to consider them in the same way.

It will hardly be necessary to say to engineers that, although the diagrams show a comparison between actual and theoretic loads, they do not show as fairly a comparison between the actual strains in a bridge in carrying these loads, as there is quite a difference in the unit strains on iron or steel used by the different specifications, probably fully as much as 20 per cent.

The diagrams do not by any means show all the engines at the Exposition, but show that the tendency is still towards heavier loads on track and bridges.

In two specifications, the Pennsylvania and the Rock Island, the effect of the two typical engines, followed by the train-load, would, in the case of the longer spans, fall below the effect of the train-load alone. In these cases the moments from the engines were calculated until the equivalent load equaled the train-load, and then the curves were continued along a horizontal line equal to the train load.

Two roads, the New York Central and the St. Louis and San Francisco, do not specify any typical engine, but use a certain load per linear foot of bridge, varying with the length of span.

The following unit strains are specified to be used in tension by the several roads named:

Railroad.	Plates and Shapes.	Bars.
A. T. & S. F.	$7\,500 \times 1 + \frac{\text{min.}}{2\text{ max.}}$	$9\,000 \times 1 + \frac{\text{min.}}{2\text{ max.}}$
Cooper	7 500 live, 15,000 dead.	8 000 live, 16 000 dead.
N. Y., L. E. & W.	$7\,500 \times 1 + \frac{\text{min.}}{\text{max.}}$	$7\,500 \times 1 + \frac{\text{min.}}{\text{max.}}$
Wabash	8 000	9 000 to 10 000, according to size of bar.
Mo. Pac	8 000	8 000 live, 16 000 dead.
Penna.	$7\,000 \times 1 + \frac{\text{min.}}{\text{max.}}$	$7\,500 \times 1 + \frac{\text{min.}}{\text{max.}}$
L. & N.	8 000 Under 20; 25%, decreasing to 5%	9 000. Impact added on spans.
C. R. I. & P.	7 000	8 000.
Frisco.	8 000	10 000.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

619.

(Vol. XXIX.—August, 1893.)

SURVEYS FOR RAILWAY LOCATION.

By F. A. GELBCKE, Engineer of Government Railways at Cologne, Prussia.

Translated from the German by R. P. MILLER, Jun. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Introductory.—Railroads, the offspring of the 19th century, have developed in a few decades with remarkable rapidity, both in the old and in the new world and have left an indelible impress on our planet. With a length of 620 000 km. (in round numbers) or more than 15 times the length of the equator, they now cover the civilized countries of the earth and still continue to branch out. Here, they press boldly into large territories not yet open to commerce; there, they weave smaller meshes into the already existing network of rails; everywhere they distribute rich blessings to the inhabitants, and hence, too, are everywhere desired. The growth of railroads is incessant and will continue, taking the whole world into consideration, for many centuries.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

The art of projecting and building railroads develops continually; the most difficult problems do not frighten us off. The natural development of railroading is that roads should enter into lands increasing with difficulties, after the simple projects, those more easily handled, have been carried out. The disposition of the immense sums spent and yet to be spent for the construction of roads is placed in the hands of engineers, who devise the plans for the roads and construct them, trusting to their scientific knowledge and their integrity of character. Hence arises the duty of the engineers to seek with untiring energy for methods by which the entrusted capital may be husbanded to the best advantage, and to invent means by which can be accomplished the greatest results with the least money.

Among the effective means at the disposal of the engineer for reducing the cost of construction must be counted the thorough study of the survey. Defective surveys, in most cases, result in an impracticable and expensive location, while thorough and systematically conducted surveys always furnish a practicable and cheapest possible location.

The following discussion purposes to describe the manner in which the engineer should conduct his surveys, in order to accomplish his object, the most practicable location. Far from any intention of discussing all the details of railway surveys, it is purposed in a few words to treat only a practicable system of executing railway surveys, and to show, on the other hand, how often surveys are still impracticably conducted. This subject seemed to the writer, in view of the great financial consequences involved, to be of sufficient importance to be presented at the International Engineering Congress.

Railway surveys are divided into general and detailed (preliminary and location). The general surveys are, it is true, preceded by general investigations (reconnaissance), and the detailed surveys (location) are followed by preparations for the construction of the road. A clear distinction of these different technical operations will prove of benefit to the thorough study of railway projects. It is therefore proposed to divide railway surveys into the following four divisions:

1. General Investigations (reconnaissance).
2. General Survey (preliminary).
3. Detailed Survey (paper location).
4. Field Location and Preparation of Expropriation Plans.

1. *The General Investigations* (*reconnaissance*).—These constitute the first problem which confronts the engineer when the construction of a railroad is proposed. Whether it be the Government, a corporation, or private individuals who desire the construction of a railroad, it must be determined whether the proposed road, as yet without definite location, will be practicable and self-sustaining, and what its estimated cost will be. In the older civilized countries useful topographical maps may be found, on a scale of 1 to 100 000, or perhaps even on a larger scale. In other countries there are probably few such maps, and the engineer is compelled to obtain a general view of the territory in question in a different manner. If a map with topographical details is to be had, it must still, in most cases, be supplemented for the purpose of the reconnaissance. The water-courses must be indicated more plainly by blue lines. The whole territory must be traversed and the comparative elevations, which are of foremost importance, must be indicated on the map. And here it may be remarked that for such preliminary level investigations barometrical measurements are especially well adapted, but, as a matter of course, they must be based on a chain of well-determined heights, which latter may, however, be widely separated. If no map is to be had, the engineer must, with the simplest possible means, make such an one. All sorts of measurements become necessary for this, and they naturally increase the expense of the reconnaissance to some extent. Finally, if the general line is to be fixed by the reconnaissance, a map of the territory in question, showing elevations, cannot be spared under any circumstances.

This map, however, will also serve other purposes. Besides the study of the practical difficulties to be met, the populations of the various cities and villages, at what points large industrial establishments, mines, forests, etc., are located, must be determined. These facts must also be indicated on the map. The population is well represented by drawing, at the points in question, circles whose areas are proportionate to the population. These circles are made more distinct by being tinted with some light color. They will then indicate almost at a glance which line is most thickly populated and which, in this respect, would offer the most practicable route for the railroad.

With such a map as just described, it will be an easy matter for the experienced engineer, considering the general, concurrently determined, condition of the territory, to make practical suggestions for the

selection of this or that route, perhaps to propose for further investigation several alternate lines; in general, to explain how the line of the road will appear, what stations it will have, how it will be operated and about how much the construction and operation of the road will cost. When a satisfactory decision has been reached, then the general investigations or reconnaissance are completed. It should here be emphasized again, that, for a really satisfactory conclusion, the preparation and use of a map in which topography, population and industries of the territory are shown, is almost indispensable. The engineer should guard against expressing judgment on the location of the road without such a carefully prepared map, thus relying on the impressions of his travels. The latter often lead on an entirely wrong track from which it is subsequently difficult to part. It is further important to include a great width of the territory to be examined and represented on the map, so that under all circumstances it will include every possible solution for the location of the road. The expenses of such general investigations are small, but on the other hand their value is very great if they are thoroughly and completely executed. They then give the assurance that nothing has been overlooked, and that routes have been proposed for construction which court further investigation and are plainly the most practicable.

In a few more words it may be stated that for the study of local difficulties it may become necessary, even in the general investigations, to represent portions of the territory on a larger scale than that used in the general map, for instance, 1 to 20 000, or 1 to 10 000. Beyond that it will seldom be necessary to go.

As far as the expenses of such general investigations are concerned, they depend on the available maps and the general characteristics of the territory to be examined. It may be asserted, however, that the engineer can undertake and complete the general investigations for the route of a railroad for 20 to 40 marks per kilometer.

2. *General Survey.*—The preliminary survey must be based on the general investigations described above, and is intended to advance the project and to decide which of the alternate lines is to be preferred. The preliminary survey furthermore serves to determine the cost of construction and operation of the road with such sufficient exactness that the capital can be furnished or subscribed, and that an excess of the cost of construction, as determined by the reconnaissance, may be excluded.

In the map of the reconnaissance the several alternate lines to be considered are shown. These must now be more closely studied and compared, and the most practicable one must finally be chosen.

In the preliminary survey are also to be investigated the nature and characteristics of very large stretches of country, measuring mostly several hundred square kilometers. The general map, on a scale of 1 to 100 000, as we have described it, is no longer sufficient, but it becomes absolutely requisite to plot the surveys on a larger scale, so that it is possible to study the course of the road more exactly, and to undertake a reliable calculation of the difficulties to be met and their cost. There are also to be obtained in the preliminary survey, above all, the measurements for, and preparation of, a map of positions and elevations which shall contain all the necessary information for the study of the project. During a long practice the writer has found that such a map is made to the best advantage on a scale of 1 to 2 500, and, under very simple circumstances, of 1 to 5 000; and that it is further of advantage for the review of the whole project to construct from these plots another general map on a scale of 1 to 10 000, indicating the road on it by a single line, and to draw along its side a profile on a scale of 1 to 500 for the heights.

Assisted by the general map (of the reconnaissance) it becomes easy to pick out the stretches of country which come into question in the preliminary survey, and of which it next becomes necessary to make plats on a scale of 1 to 2 500. In this connection care must be taken that the limits of these stretches are not taken too narrow. Thus, a greater extent of measurements and the corresponding plats become necessary in the case of flat country or of water-sheds than in the case of narrow valleys, in which only a narrow strip of land can enter into the question of the location. It is recommended in the case of narrow valleys always to consider both slopes of the valley in the extent of the survey.

Since then, in the preliminary survey, we deal with the measurement of extended areas, and since, on the other hand, a precise determination of heights, even with reference to the scale of the plats, is not at all requisite, the barometer is here exceedingly well adapted for the determination of levels. In the hands of an experienced engineer it is an instrument of extraordinary efficiency and sufficient accuracy. The engineer himself, furnished with a barometer, must mount all heights

to be determined, and in this way he also acquires a comprehensive knowledge of the country, quite invaluable in the study of the general project. Other methods which can be applied in preliminary surveys may be mentioned; as, for example, plane table surveys, or notes by means of the tachymeter; or, finally, and to be least recommended, cross-section measurements. But none of these methods are so well adapted for preliminary surveys as barometrical measurements. The writer would here describe, in a few words, an approved, though unfamiliar, procedure of the barometrical determination of heights, for the purpose of preliminary surveys.

The equipment of a corps of about five engineers for undertaking barometric measurements for the purposes of the preliminary surveys is, considering the rapidity of progress, comparatively simple, and consists of four levels and level rods, three sextants, two plummets, two tape measures, twenty ranging poles, five leather bags, about eight aneroid barometers, one or two barographs, and three sling thermometers for the determination of atmospheric temperature; lastly, every engineer must be provided with a good pocket timepiece. Every engineer should have but one assistant, whose duty is chiefly to carry instruments and keep field notes.

The determination of heights by means of the aneroids, to be reliable, must rest on a network of elevations which have been determined by the spirit levels at such distances that at intervals of from half to one hour the readings of the aneroids can be taken at such points. For the determination of changes of atmospheric pressure during the work the barographs are used, that is, aneroid barometers, which automatically register the pressure on a strip of paper moved by clockwork. The barographs may be dispensed with if the determined heights are taken so close that every engineer in the field can read his aneroid at one of these fixed points, not less often than every half hour. Under these circumstances it may be generally assumed that the pressures change regularly in the meantime. In the determination of heights for engineering purposes, the aneroids of Naudet, of Paris, Bohne, of Berlin, and Hottinger, of Zürich, and especially those of the last-named manufacture, have proved most satisfactory. The work is much simplified if the aneroid is independent of temperature, a condition which Bohne, of Berlin, has almost accomplished by means of a compensating attachment. But all aneroids which have thus far been

in use change their readings with time, and it is, therefore, absolutely necessary to subject all the instruments, before every campaign (*i.e.*, once a year), to an examination and to make new correction tables for them.

The measuring of heights with the aneroid always presupposes the existence of a map of the territory in question, or that the positions of the stations, whose elevation is desired, are easily determined. If there are maps, as, for instance, maps that show the ownership of property, they are to be used drawn to a scale (say, 1 to 2 500, or 1 to 5 000), and for further use they may be manifolded to great advantage by some printing process. It has proven disadvantageous to make the separate sheets more than 1.2 m. long and 0.60 m. wide. If no maps are to be had, nothing remains for the engineers but to lay out a network of lines over the whole of the land to be measured; to put on paper this network, which also should contain the elevation stations, on a scale of 1 to 2 500 or 1 to 5 000, and to fill in the meshes of this network by the use of the pedometer at the time of making the aneroid measurements. In either case, where there is or is not a local map, the determination of elevations by aneroids must be preceded by a line of levels obtained by spirit levels, which needs, however, follow only approximately the prospective route without strained exactness, but which, for the sake of certainty, must be made by two engineers, independently, and the purpose of which is to establish bench marks at distances of about 200 or 300 m. For the elevations of the leveling of n kilometer distances, an approximation of $80\sqrt{n}$ millimeters will be sufficient.

On account of the great width of the territory to be surveyed (about 1.5 km.), the principal line of level must furthermore be supplemented by various secondary lines of leveling, which are to be connected with the principal line at various points, and must contain most of the easily accessible bench marks. Great accuracy is not required in the secondary lines. In a distance of 2 km. an error of 20 cm. may still be admitted. The elevation stations of the secondary lines are also to be distinctly entered on the field map.

We can now proceed to the barometric leveling. Barometers are intended for the measurement of atmospheric pressure, which is dependent, not only on the elevation of the point of observation, but also on various other circumstances, and is also variable in time.

Now, if observations of the atmospheric pressures are simultaneously made at two points which are not separated very far in space (the best practice is not to exceed 15 km.), the difference of the observed pressures will correspond to the weight of the column of air which lies between the two horizontal planes passing through those points. The height of this air column equals the required difference of elevation between the two points. It can be calculated, according to a formula based on experience (the so-called barometric formula), if the pressure at each point of observation is known, besides the mean temperature of the air column.

If a barograph is used in connection with these observations, it is so set up that it is about at the center of the field to be measured, and that the engineers with the aneroids do not get farther away than 15 km. at the most; otherwise the position of the barograph must be changed.

In carrying out the measurements, the engineer begins with some determined bench mark of the local map, looks for that point in the field, and at the same observes the time, the aneroid temperature, and the reading of the aneroid, after having lightly tapped the same, to cause the instrument to work freely. The field map or plan is fastened to the portfolio that the assistant carries. The assistant also has a timepiece hung from his neck. Lead-pencil and pedometer are tied to the coat of the engineer, that he may have his hands free for the measurements.

Having started from well-determined stations, the intermediate stations of the territory can be located by pacing and comparison with the distances on the field map, and recorded, in the case of a simple configuration of the ground, for every 50 double paces (100 yards); but in the case of more complex configuration more frequent points are required, by pacing the border lines or simple construction lines, and the heights must be determined barometrically.

The line to be followed by the observer is previously determined by the condition that inside of a half or one hour at most, the reading of the aneroid must again be taken at some bench mark, that is, some station of well-determined elevation. The extent of the territory to be measured in the meantime depends on the skill of the observer, the clearness from obstructions, the worth of the aneroid and the configuration of the ground. After a little experience, the engineer can easily tell at a glance which line to follow.

For the certain determination of heights, it is also important to take so-called check stations, that is, to repeat barometric observations at some point after a lapse of time (for instance, after one or two hours), thereby obtaining a check on the change of pressure and on the correctness of the readings of the aneroid.

One engineer of average experience, with an assistant, can locate and determine the elevation of 100 stations in a hilly district in one day. Very experienced observers can accomplish double that amount. The stations lie on an average of 50 to 60 double paces apart (100 to 120 yds.).

For the determination of atmospheric temperature, the sling thermometer, already mentioned, is used, by swinging the same on a string in the atmosphere, in a shady spot, until it indicates a stationary temperature. According to the season and the geographical location of the place it becomes necessary to make these temperature observations two or three times a day.

The calculation of the heights of the barometrical observations is done most satisfactorily by graphical means. The aneroid readings, corrected for temperature, are plotted on cross-section paper. On these, with the aid of the notations of the barograph and the readings at the bench marks and check stations, a horizontal curve is constructed. Thus, an aneroid diagram is formed, from which it is only necessary to read the ordinates of the curve at the stations on the diagram, with a scale varying to suit the observed changes of temperature of the day, in order to obtain the elevation of the stations. This graphical diagram was invented by Engineer Steinach, and described in detail by the inventor, in 1881, in the first number of *Zeitschrift des Architekten und Ingenieur-Vereins zu Hannover*. It furnishes the desired results quickly and without any calculation, so that large errors in the determination of elevations are completely excluded. Concerning the accuracy of the aneroid measurements—for instance, those of aneroids of Hottinger—variations of pressure corresponding to 0.01 mm. of quicksilver, or about 0.1 m. of elevation, can be read, although it is not possible to carry out such accuracy in the field. Experience has shown, however, that a careful observer is able to reach an approximation of 1 or 2 m. elevation with certainty, which, on the scale of 1 to 2 500, 1 to 5 000, or even 1 to 10 000, chosen for the plat, is sufficiently close. The view often advanced, that the

aneroid does not offer sufficient accuracy for preliminary surveys, is unfounded.

After the heights have been determined, the entering of the elevations and contours in the plat, and the completion of the plats on a scale of 1 to 2 500, follow. The contours are entered for every 5 m. elevation, and are drawn in a striking color, for instance, red, and every fifth contour is drawn heavier. In the plats of 1 to 2 500, roads, watercourses, buildings, the limits of built-up localities, or other important limits are now entered, relatively elaborated, and, as far as necessary, also indicated by written notes. Furthermore, the high water-marks on bridges and buildings or other places are written down in blue; so, too, the width and height of every existing bridge and of every culvert is given. In the plat are also indicated, by suitable notation, all unusual topographical details, as the existence of rock masses, the strike and dip of rock strata, slides, swamps, springs, quarries, pits, etc., which are of importance in the study of the location. A contour map made up in this way on a scale of 1 to 2 500 forms an excellent basis for the study of a general location and for the calculation of the cost of construction of the railroad.

To give a description of the study of the general project would carry us too far. But it must here be emphasized, that the line selected must surpass all its competitors in best adapting itself to the configuration of the land, and that the final result must be the unquestioned designation of that line as above all others the one which can be advanced as the most practicable. It is to be further remarked that the staking out of the line in the field is not necessary in the preliminary survey; it should even be avoided, as all facts can be taken from the map, and only in the latter is a superficial study possible. The transferring of the line to the field has no purpose; it may even injure the progress of the whole enterprise in that the adjoining property-owners are put in a position to speculate with their property.

Along with the execution of the preliminary work, the general estimate of cost is to be made, and the previously reported statement of the needed capital is to be corrected and supplemented. The route is finally to be put down in a map on a scale of 1 to 10 000; and a profile on a scale of 1 to 10 000 for distances and 1 to 500 for heights is to be made. Of the larger structures and of the track and switch work of

the yards, sketches are to be made for estimating their cost. Preliminary surveys, made in the above comprehensive manner and offering most certainly the best practicable solution, cost, according to the writer's experience, from 100 to 200 marks per kilometer.

Of all the preparatory work for the construction of the road, the preliminary survey is the most important of the engineer. If carried on in the proper manner, there is no danger that the location of the road must be later designated as a failure. Still, the detailed work to be described hereafter is also important and must likewise be carried out with a care corresponding to its purpose.

3. *Detailed Survey.*—This rests on the preliminary surveys, as these were based on the general investigations or reconnaissance. They constitute a further step towards arriving at the plan of the road. For this purpose the location of the line must be examined in greater detail, for which again plats on a larger scale are necessary. The next duty of the engineer consists in making surveys, and from these to prepare study maps which shall contain everything that is necessary for the study of the detailed project. A suitable scale for these study maps is 1 to 1 000. From the preliminary survey the approximate location is known. The detailed study of the project requires an exact survey of a strip of land from 100 to 200 m. wide in which the smaller width is to be taken for heavily sloping land, the larger for flat land.

As in the preliminary survey the barometer was mentioned as the instrument best adapted for the work, so for the surveys for the detailed work the tachymeter is best adapted, that is, a theodolite furnished with stadia wires.

The available force of engineers and assistants is divided, in tachymeter measuring, into small parties. Each party consists of two engineers, a recorder, a boy for holding the umbrella and for giving signals, and two or three rodmen. For the equipment of each party there is necessary, a tachymeter, with tripod and hood, a plummet, an instrument umbrella, a camp stool, a tape, two or three telemeter rods with plummets or pocket levels and stakes for securely setting up the rods.

The field work begins with laying out a traverse line which approximately follows the proposed line. The levels of the intersection points of the traverse are exactly determined and serve for all further work

as bench marks; consequently, they are to be fixed as securely as possible.

When the traverse line is staked out, secured, measured and leveled, it is plotted on a scale of 1 to 1 000, and the real tachymetrical survey then begins. In the work, one of the engineers of each party is stationed at the instrument, takes the readings, calls them off to the recorder who stands beside him, and has the umbrella boy give the necessary prearranged signals to the other engineer who is with the rodman, to give them the necessary directions. The second engineer carries the field book and records in it all the notes of the determined and consecutively numbered stations, and supplements it by intermediate distances which are necessary to work up the plot.

For the rapidity and usefulness of the tachymetrical measurements it is important to keep in view that the heights of the land must be obtained from comparatively few well-determined stations. By means of the tachymeter every desired point of the field can be quickly determined with regard to position and elevation; therefore the capability of the tachymeter is very great. According to the writer's experience, it may be asserted that practiced engineers in a field with not too many obstructions can, in one full working day, determine about 600 points.

The calculation of the tachymetrical stations, in other words, the reckoning of the distances from the instrument stations as well as the elevations, may be made by means of tables, or by logarithmic slide rules, or by the tachymetrical scales, based on graphical methods of Engineer Teischinger * or of Engineer Puller.† Since by the use of the tachymetrical sliding rules almost all calculations can be avoided, and the scale directly shows the elevation and horizontal distance, the reckoning with the two tachymetrical slide rules is to be preferred in extended surveys above all other methods, as the most reliable, most convenient and most rapid.

For plotting the notes, the sheets with the plotted traverse line on a scale of 1 to 1 000 are used. The plotting is started from the traverse station corresponding to instrument stations by means of protractors. In this way a map is developed on which, finally, contours of 1 m.

* Described in No. 4, 1883, of the "Zeitschrift des österreichischen Ingenieur u. Architekten Vereins."

† No. 4, 1888, of the "Zeitschrift des Architekten u. Ingenieur-Vereins zu Hannover."

difference in elevation may be sketched. Every fifth contour is drawn more heavily than the rest. As a matter of course, the map must show all determined points with their elevations, all objects necessary for the detailed location, roads and water-courses, bodies of water and flood points, buildings, bridges and culverts, farms, important boundaries, strike and dip of rock strata, rock masses, slides, swamps and moors, and all must be plainly described. In order to judge after the plotting, whether the surveyed and plotted territory is sufficient for the study of the location, it is necessary to lay out a preliminary line. If it then becomes apparent that the spread of the survey is not sufficient, supplementary surveys are to be undertaken at once.

For the study of the detailed location, exact knowledge of the nature of the soil where the road is to be located is of importance. Therefore, test pits along the preliminary line are to be made in all the larger cuts and the nature of the soil and rocks determined, in order to decide what slopes are practicable, and what the cost of moving will be. For the investigation of the capability of the ground to carry weights, test-pits must also be made at the base of high embankments and at places where large structures are to be located. The test-pits are likewise to be indicated in the map, and the result of the examination of the pits is to be noted on the edge of the map.

By this time the field work may be considered completed, and the engineer, aided by the study map on a scale of 1 to 1 000, proceeds to a thorough study of the location. All requisite notes he takes from the maps on which by various trials he seeks the most practicable location of the road. As necessary, he can take every required profile or cross-section from the map and can make the earthwork calculations. From the notes of the map he is also able to design and estimate on all the structures. Thus the detailed location of the road and the detailed estimate are arrived at without the necessity of locating the line of the field, to which favorable circumstances especial attention will hereafter be called. The study is made from the maps of 1 to 1 000, and is also laid out on this scale. Copies of the maps are made, and the location is entered on them. The scale is large enough to indicate also the adjacent ground. For a general view of the whole road, the scale of 1 to 1 000 is, however, too large; therefore, it may be suggested, as it is often done, to prepare, besides, a general plan on a scale of 1 to 2 500, which is best done by photo-

graphic reduction. These maps will contain the complete presentation of the road, and are supplemented by a superscribed profile of the line on a scale of 1 to 2 500 for the distances and 1 to 250 for the elevations.

Detailed surveys, which are made in the manner above described, cost, according to the writer's experience, from 1 000 to 2 000 marks per kilometer.

4. *Field Location and Preparation of Expropriation Plans.*—The next work of the engineer is the transferring of the line to the field, in accordance with the location, as made on the plats of the detailed surveys on the 1 to 1 000 scale. The staking-off starts from the traverse line given in the field and in the maps. According to the accuracy of the maps, it is easily found that the line as transferred to the field corresponds to its location as given in the plats. The length of the line in the field will, however, always differ somewhat from the plotted line; still, never so much that the general map (scale 1 to 2 500) becomes useless. The division of the road, doubly measured in the field for the sake of certainty, is afterwards distinctly shown in the plats of 1 to 1 000, and is made the basis of the construction.

After the line has been staked out, numbered and secured by reference points, a profile of it is made by connecting with the bench-marks of the traverse line. This work is followed by the cross-sectioning at right angles with the line. Consideration of the suitable location of the cross-sections must be had during the staking out of the line, and it must be remembered that the exactness of the earth-work calculations depends, not on the number, but on the correct position, of the cross-sections. These are intended only for the construction of the comparatively narrow roadway, and are, therefore, to be extended only for short distances on each side of the line. The drawing of the profile is made with most satisfaction on the scale of 1 to 2 500 for distances and 1 to 250 for height, while the cross-sections are made in undistorted form on a scale of 1 to 200. Both profile and cross-sections are provided with the notes of the survey and are utilized to arrive at the earthwork calculations necessary for the immediate construction of the road.

The transference of the line to the field, just described, is followed by the measurement, plotting and finishing of the property plans on a scale of 1 to 1 000 and the preparation of the lists for the acquisition

of the property. The property plans are surveyed along the tangents of the line and are connected with adjacent property.

Before the construction of the road is begun, it becomes necessary again to subject the detailed location to another examination, and at places to improve and supplement it. This is followed by the preparation of working drawings, specifications and the formulating of contracts, etc. But this work is no longer to be counted a part of the survey of the road, but rather of the construction. It may, therefore, be assumed that the survey closes with the measuring and preparation of the expropriation plans. In the case of each of the three previous divisions of the survey, the approximate cost of the work for 1 km. of road was given at the end. So here, too, it is to be stated that the staking out of the line and the preparation of the expropriation plans, as still belonging to the survey, together are to be estimated at about 400 to 800 marks per kilometer.

The total cost of the survey would add up, according to the preceding figures, about as follows:

	Cost of 1 km. of road.
General investigation.....	20 to 40 marks.
Preliminary survey.....	100 " 200 "
Detailed survey.....	1 000 " 2 000 "
Field location and preparation of expropriation plans.....	400 " 800 "
Total cost of survey	1 520 to 3 040 marks.

That is, properly and thoroughly conducted surveys for railroads cost according to smaller or greater difficulties, under mid-European conditions, about from 1 500 to 3 000 marks for each kilometer of road.

With this the writer ends the discussion of a practicable method for making surveys for railroads, as proposed in the introduction. Basing his opinion on experience, he is convinced that those engineers who pursue it will soon appreciate the great advantage of the method by which we proceed step by step from the general to the particular. The investigations are accomplished in a quiet and satisfactory manner, and, with the least competency of the chief engineer, a failure is completely avoided. In conclusion, let us make a short freview of the method of work, and show in a few words how surveys or railroads are contrary to the accepted rule, still often pursued in an impracticable manner.

In an abridged form, the writer proposes the following rules for surveys for railway locations :

Firstly.—General investigations are to be made, which must cover a large territory containing all possible alternate lines. For this purpose a review map of 1 to 100 000 is prepared, in which the topography is represented and in which all important elevations are to be shown. Result; proposal of various alternate lines with estimate of cost of construction and operation of the road.

Secondly.—General Surveys.—The alternate lines suggested by the general investigations are more carefully examined by general surveys (preliminary). For this, surveys of large stretches of land and study maps with contours, on a scale of 1 to 2 500 or 1 to 5 000, by means of aneroid barometers, are made. Study of the general project in these maps and presentation of them on a scale of 1 to 10 000 for a ground plan, with a profile on a scale of 1 to 500 for height. The line is not transferred to the field. Results of the preliminary survey—selection of the most practicable location, general plan on given scale, general estimate of cost with reliably sufficient total cost and estimated income of the road.

Thirdly.—The Detailed Surveys.—The general line is more closely studied, its most practicable location still more accurately determined. For this, surveys by means of the tachymeter, of a strip of land from 100 to 200 m. wide, are made. Exact maps or plats (study maps with contours) on a scale of 1 to 1 000, soil investigations, etc., are made. Study of the detailed line in the above-mentioned maps of 1 to 1 000, and, as in the case of the general survey, without staking off the line in the field. Drawing of the detailed route in the maps of 1 to 1 000, as also for general review purposes in the maps of 1 to 2 500, to which is added a profile of 1 to 250 for heights. Results of the detailed surveys—exact determination of the most practicable location, detailed plan of the same and adjacent territory, detailed or principal estimate of the cost of the road.

Fourthly.—Field Location and Preparation of Expropriation Plans.—This division comprises the transferring of the line into the field, as determined in the exact plates, measuring of length and elevation of the located line, measuring and drawing of short cross-sections, indicating of the line in the cross-sections and profile, further testing and supplementing of the route; finally, measurement and preparation of the

property maps and making list of properties to be acquired. Result: Detailed and thoroughly prepared route of the road for those intending to construct it, the line of which has been transferred to the field.

It is to be added that the foregoing rules prescribe the measurement at first of general, then of plots of gradually increasing, exactness, in which the choice of lines may be made, and their study may be accomplished; whereas, the staking out of the line in the field and the measurement of profile and cross-sections cannot be undertaken till the end, and then only when the exact location of the line in the plots is finally determined. This will not only avoid the premature and unnecessary transferring of the supposed line to the field, and the making of unnecessary cross-section measurements, but it will especially meet the danger of locating in the field and building accordingly a line lacking previous comprehensive and thorough examination and investigation. This danger is always present, if the chief engineer has transferred to the field any line, according to his views perhaps the most practicable one, without having previously investigated it first in general, then in detailed, maps. Unfortunately this still frequently occurs. It is thought that dependence can be placed on a practiced eye, on traveling impressions, etc. It is intended perhaps also to greatly simplify the procedure of the surveys, and it is hoped to attain the result more rapidly, if the trouble of the preparation of comprehensive maps and the examination of the lines by means of them is dispensed with; in short, it is assumed that the best location can be obtained without long investigation, and acting on this supposition the line is located at once in the field. The line is measured, cross-sections are measured and drawn, and the project is worked up according to the location in the field. Thus the unfortunate step to an unfavorable solution is made.

It soon becomes evident that the line as located in the field is not altogether practicable. Then adjustments of the line within the limits of the cross-sections are attempted and if these get too far from the original line, nothing remains but to partially stake out a second trial line and to repeat the measurements and calculations for this one, again without good results. In this way adjustments and new trial lines follow one another, until finally a practicable route is developed. Practicable it may be, but who will vouch for it that it is the most practicable of all possible routes? No engineer who has made his

surveys in the faulty manner just described can say that. He has no idea whether the road could or could not be carried out in another location and perhaps very much cheaper, outside of the reach of his limited survey. It may even be asserted with certainty, that by his procedure he has not attained the result that might have been attained. The road, as nothing better is known, is brought to construction, and costs much more than it would cost, if its location had previously been properly examined on the maps and plots, step by step, first in general and then in detail and in a thorough manner, according to the given rules.

The surveys for railroads should, therefore, not be regarded lightly, and any movement toward staking out a supposed practicable line, without previous and through investigation from comprehensive maps should be especially guarded against. In most cases success in finding the location which is the most practicable, and which, when constructed, costs comparatively least, does not follow from too early a location in the field.

The cost of thoroughly prepared surveys is seldom more than the cost of defective surveys which rest on a line too soon located in the field, and the difference disappears when compared with the amount which is saved by a practicable location founded on good surveys.

There may be very simple cases in which one can proceed directly from the general study to the field location. These cases are, however, rare, and the writer would advise his colleagues to do a little extra work in the thoroughness of the surveys rather than too little. Good surveys pay well in all cases. Most dangerous to success is it, however, when the chief engineer undertakes to shorten even the reconnaissance, and before making the latter, if such is possible, endeavors to lay off a line in the field.

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(Vol. XXIX.—August, 1893.)

A NEW METHOD OF CALCULATING CROSS-SECTIONS OF ROADS AND RAILROADS.*

By FRANCISCO DA SILVA RIBEIRO, Director of Public Works, Aveiro, Portugal.

Translated from the French by FOSTER CROWELL, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In the calculation of cross-sections of roads and railroads strict accuracy is an impossibility, whether we plot them and determine the areas rigorously, or whether we obtain the areas from diagrams prepared by graphic methods; because the basis of the calculation, the shape of the ground, cannot be given exactly, owing to the innumerable deviations in the outline of the leveling.

* *Note to the English reader by the translator.*—This method of computing cross sections is only applicable to measurements made with the cube unit; in connection with American and English practice it would be necessary to have the diagram verticals at intervals of 1 yd. and the scales plotted to yards and decimals.

Wherever the metrical system is used the great advantages of the method are manifest. —F. C.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

The best practice is therefore the most expeditious one that will give us a sufficiently close approximation, and from this point of view our system, proved by long experience, appears to be entirely satisfactory. In effect our diagrams can very easily be drawn, for each different width of roadbed and inclination of the slopes, so as to furnish by simple readings the widths for the expropriations and slope distances, both at the regular stations and intermediately, and at the same time the partial areas the sum of which is the total area of the cross-section; the inclination of the ground may be regular or irregular. These, then, are all the conditions necessary for simplicity and completeness.

The plotting of the diagram is accomplished in the following manner:

Let $a\ b\ c$ (Fig. 1) be any half cross-section, divided by vertical lines at intervals of 1 m. and intersected by the center line of the road.

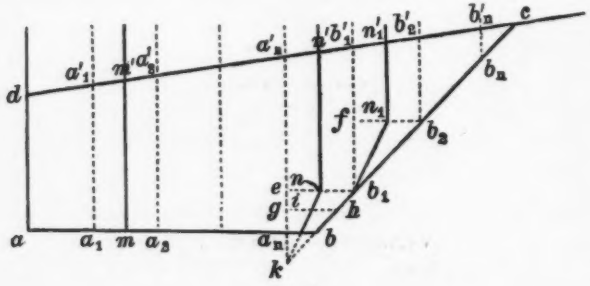

FIG. 1.

We will designate by $a_1 \ldots\ldots a_2$ the feet of the verticals intersecting the platform (formation level), and by $b_1 \ldots\ldots b_2$ those of the verticals which cut the slope.

In general, the surface line determines the figure of the rectangular trapezes such as $a_1\ a'_1\ a'_2\ a_2$; the pentagon $a_n\ a'_n\ b'_1\ b_1\ b_1$; the trapezes, of the form $b_1\ b'_1\ b'_2\ b_2$, and the triangle, $b_n\ b'_n\ c$, wherein the height is less than, or equal to, 1 m.

The areas of the rectangular trapezes, whatever may be the surface-line, are obtained correctly by means of the median lines $m\ m'$; so that if we measure by scale each one of these lines, starting from zero on

$a\,b$, we may obtain the total area $a\,d\,a'_n\,a_n$, by adding together all the readings of the amounts given by the scale.

The pentagon and the trapezes on the slope can be resolved into two parts, one of which is a rectangular trapeze $e\,a'_n\,b'_1\,b_1$ or $f\,b'_1\,b'_2\,b_2$, given by the mid height $n\,n'$ or $n_1\,n'_1$. It now remains for us to determine the areas contained in the trapeze $a_n\,e\,b_1\,b$ and in the triangles $b_1 f\,b_2$, for which we employ an approximative process.

Considering the trapeze let us assume—

a the constant side, $a_n\,b$ of the successive trapezes $a_n\,b\,h\,g$;

x the variable height, $a_n\,g$ of the trapezes;

A their surface;

t the natural tangent of the slope-angle from the horizontal;

We have $g\,h = a + \frac{x}{t}$ and it follows:

$$A = \frac{2\,a + \frac{x}{t}}{2}\,x$$

or

$$x^2 + 2\,a\,t\,x = 2\,A\,t.$$

We deduce from this equation—

$$x = \sqrt{a^2\,t^2 + 2\,A\,t} - a\,t.$$

By adopting a scale of $\frac{1}{50}$ we can readily estimate to $\frac{1}{20}$ of a cubic meter. It will suffice now for us to substitute $A = .1\,.2\,.3$ ..... up to the value—

$$A = \frac{(1 - a^2)\,t}{2}$$

corresponding to $x = (1 - a)\,t$.

The successive values of A are to be laid out upon the median line $n\,k$, the point k being the intersection of the slope-line with the vertical $a_n\,a'_n$.

For the triangles $b_1 f\,b_2$, we make $a = o$ in the preceding formula, and obtain— $x = \sqrt{2\,A\,t}$,

and the limiting values of A and of x

$$A = \frac{1}{2}\,t \text{ and } x = t$$

we lay out these values on the median lines $n_1\,b_1$.

In this manner wherever the surface-line cuts the median lines $n\,k$, $n_1\,b_1$, we take for the areas of the respective figures the numbers inscribed upon those lines. The errors are insignificant.

We will next examine the case where the platform $a\ b$ is crossed by the surface-line.

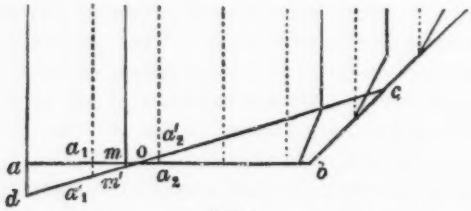

FIG. 2.

Besides the areas previously considered we find the triangles $a_2\ a'_2\ o$ and $a_2\ a'_2\ o$. We may admit approximately that the first is represented by the side $m\ m'$ shown on the corresponding scale, and consider the second null. In effect the greatest amount of this error is when the point o coincides with m; this applies both to fill and cut. For if we designate by i the surface inclination, we find in this case—

$$a_2\ a'_2 = .50\ i$$

and triangle $0\ a_2\ a'_2 = .25 \times .50\ i = .125\ i$; a negligible quantity.

We have now the necessary elements for constructing the diagram.

Upon the axis of the road, and also at a distance of 10 m. (by scale) therefrom (see Fig. 3), we lay out the scales intended for the elevations on the axis and the inclination of the ground. The line of the platform (subgrade line) is also furnished with a scale for the widths of the expropriation. The slope $b\ c$ may have another for the lengths as regulated or as they may occur.

If we employ quadrille paper (paper ruled in squares) this last scale may be obtained from the vertical by means of values of x deduced from the equation—

$$x^2 + \frac{x^2}{i^2} = D^2,$$

or

$$x = \frac{D}{\sqrt{1 + \frac{1}{i^2}}}.$$

Finally we remark that the section of the ditch for draining the surface of the cut is given by diagram.

The diagram (Fig. 3) is designed for a roadway of 6.6 m. (21.65 ft.) in width between ditches. It gives the surfaces of cut, the width of

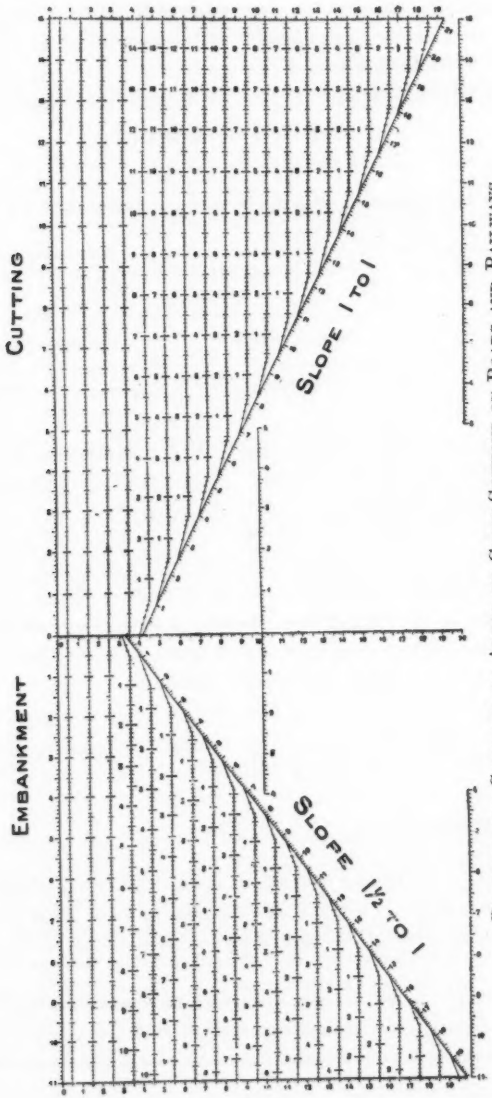

Diagram for Calculating Areas of Cross-Sections of Roads and Railways.

Fig. 3.

ditch being .9 m. (3 ft.) and the slope-angle is 45° (1 to 1); the surfaces of the fill have a slope of $\frac{2}{3}$ of height for 1 of base ($1\frac{1}{2}$ to 1). The vertical scale is twice the horizontal.

Making in our formula—

$$a = .2 \text{ and } t = 1 \text{ for the cutting,}$$
$$a = .3 \text{ and } t = \tfrac{2}{3} \text{ for the fill,}$$

we obtain the following data to be used in laying out the median lines:

Values of A.	Values of x.			
	Cutting.		Embankment.	
	Trapeze.	Triangle.	Trapeze.	Triangle.
0.10	0.290	0.447	0.216	0.365
.20	.463	.632	.314	.516
.30	.600	.775	.463	.632
.303	.....	.....	.467	.....
.333	.....	.....	.....	.667
.40	717	.894	.564	.734
.48	.800	.....	.....	.....
.50	.820	1.000	.664	.834
1.00	1 320	2.000	1.164	1.334

The values of the coefficient of the length of the slope are—

$$\frac{1}{\sqrt{1 + \frac{1}{t^2}}}$$

for the cutting..... $\sqrt{\frac{1}{2}} = 0.7071$

for the embankment..... $\sqrt{\frac{2}{13}} = 0.5547$

In order to avoid having the scale of the inclinations encroach upon the slope we have set a part of it at a distance of 20 m. from the axis; the plotting apparently doubles the respective slopes used in the diagram.

The readings on the median lines may be made by stretching a thread with pins or with weights, furnished with hooks at the base. This method enables us to calculate as many as 200 cross-sections in a day.

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ON THE GAUGES OF RAILROAD TRACK IN GENERAL, WITH SPECIAL CONSIDERATION OF NARROW-GAUGE RAILROADS.

By E. A. ZIFFER, C. E., of Vienna, Austria.*

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Translated from the German by WOLFGANG G. TRIEST, Jun. Am. Soc. C. E.

Evolution of the Railroad Gauge.—Many text books, pamphlets and engineering papers contain a bountiful supply of scientific discussions, based only partly on practical experience, on the selection of the gauge which generally exercises a determining influence on the construction and running expenses as well as on nearly all proportions of a railroad. It is, however, somewhat difficult to obtain from the existing

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NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

material the nucleus of the considerations at issue, especially as regards the newer creations, the narrow-gauge railroads, and thus find new points of view for this most important subject.

Before approaching this question more closely, which is not only purely technical, but essentially an economic one, the writer may be permitted to present a historic retrospect on the evolution of the railroad gauge.

The selection of the gauge of 4 ft. 8½ ins. (1.435 m.), measured between heads of rails, which George Stephenson took in 1825 for the first locomotive, built at his Newcastle shop, for the first public railroad from Stockton to Darlington,* and in 1830, for the railroad from Manchester to Liverpool,† is not the result of technical considerations, but is only the adoption for railroad purposes of the gauge customary for road wagons in North England; it was accidental.

This gauge, sometimes wrongly named "German gauge," originated, therefore, in England. It was introduced as "Stephenson's gauge" into most European countries, and became international in 1886, at the international conference for technical units in railroads. It is designated as "standard" or "full gauge." In 1846 it had already been ordered, by Act of Parliament, for all English railroads then under construction or to be thereafter constructed, except for those in the counties of Cornwall, Devon, Dorset and Somerset.

It has been recognized that this gauge is more in accordance with the ordinary demands of freight traffic because with its use the loading capacity of the freight cars, conditional on the gauge to a certain degree, corresponds better to the customs of commerce than with the 7-ft. (2.134-m.) gauge. The latter was introduced by Isambard Brunel,‡ on the London-Bristol division of the Great Western Railway in 1836. The origin of the different gauges of Great Britain is due to the fact that engineers have partly followed Stephenson's example, and partly that of Brunel. With the primitive status of the track and rolling stock of those days, the broadest possible basis

* September 27th, 1828, must be regarded as the birthday of the present railroad system, when the first passenger train was drawn by a locomotive over the railroad from Stockton to Darlington, 41 km. long, at a speed of 10 km. per hour. This road had, however, been in use since 1825, but until that day had been used for the transport of coal and ore only, the same as the other railways of that time, which were mostly operated by horses.

† This was the first railroad built from the start for a general passenger and freight traffic. It was opened on September 15th, 1830.

‡ Dr. Röll's Encyclopädie d. ges. Eisenbahnwesens (Biographie Brunel), II Band, 1890.

seemed necessary for stability, as it was supposed that the stability of the car and the speed attainable would increase with the angle of stability, viz., the angle formed by lines drawn from the center of gravity of the car to the heads of both rails. This consideration may be regarded as outgrown by the present high development of iron construction and manufacture. The scope of the mistake of having taken several gauges was, however, not realized, until the railroads with varying gauges were so enlarged as to join each other. Then it became evident that differences of gauge rendered the uniform operation of such a system of railroads entirely impossible and entailed such disadvantages as to compel the adoption of a standard gauge.

The Development of Gauges in Different Countries.—In spite of this, there were in use until recently, in England and Wales, the following different gauges besides the standard gauge, viz.: 1 ft. 11½ ins. [(0.597 m.) Festiniog and North Wales Railway], 3 ft. (0.914 m.), 3½ ft. (1.070 m.) and 4 ft. (1.220 m.); in Scotland, 4 ft. (1.220 m.), 4 ft. 7¾ ins. (1.416 m.), and 4 ft. 7⅝ ins. (1.413 m.); in Ireland, 3 ft. (0.914 m.), 4 ft. 8 ins. (1.422 m.), and 5 ft. 3 ins. (1.600 m.). It must be mentioned, however, that these different gauges are in operation only on secondary and tramcar lines and on industrial railways. The Great Western Railway has entirely abandoned the broad 7-ft. (2.134-m.) gauge, by changing to standard gauge, in May, 1892, its last broad-gauged division from Exeter to Falmouth, 270 km. This feat was accomplished by 5 000 workmen in 31 hours, including a Sunday, so that there was little interruption in the operation of the road. The narrow-gauge railroads in the large shops at Crewe and Chatham with a gauge of 1 ft. 6 ins. (0.460 m.) may also be cited, and, as a curiosity, the transportation road of the iron works of the Furness-Abbey Company, which has a miniature gauge of only 8 ins.

For Ireland the gauge was fixed at 5 ft. 3 in. (1.6 m.).

France adopted a standard gauge in 1828, and the majority of its railroads have been built with a gauge of 1.5 m. between rail centers. This is a very inconsiderable deviation from normal gauge, as the gauge will vary between 1.44 and 1.45 m., according to the width of rail heads. At present, a clearance of 1.44 m. between rail-heads is exacted. The movement to make narrow-gauge roads acknowledged members of the European railway system dates from the year 1851, but the narrow gauge was first used by the engineer Sartiaux, in 1874,

on the passenger and freight railroad from Neuilly-en-Thelle to Beaumont. This line contributed largely to the development of the 1-m. gauge railroads, thanks to the energy of Civil Engineer Level.*

Narrow gauge was not used on a main line (*chemin de fer intérêt général*) before 1885, when it was taken for the railroad from Châteaumeillante la Guerche to Sancoins la Peyrouse. The law of 1880 did not fix the gauge, but discriminated between railways over which the rolling stock of the trunk lines could or could not pass.

The specifications for railways, however, provide for gauges of 1 m. and of 0.75 m., in addition to standard gauge, and thus enable the roads to obtain different gauges suitable to different demands. The above regulation was suspended in 1891, and, besides standard gauge, only gauges of 1 m. and of 0.6 m. were declared admissible. The latter has been recently chosen for secondary (*chemins de fer intérêt local*) and for strategic railways. Very recently (August, 1892) the 0.8-m. gauge was chosen for the secondary railroads of the Department of the Ardennes. The industrial railways also use gauges of 0.5 m. and upward; finally, the Lartigue system, a one-rail railroad, consequently a road without any gauge, should be mentioned. A charter has been given for a railway on this system from Fleurs to La Panissière, 17 km., and the right of eminent domain was declared for it.

The Franco-Algerian Railway had adopted the gauge of 1.055 m. in 1872; but, since 1877, the 1-m. gauge has been in exclusive use in Algiers. In 1861 the French Government had ordered an "*enquête*," which should furnish a strong stimulus to the building of secondary railroads. Considerable merit is due to Eugen Flachat,† one of the most prominent members of the commission, who advocated the use of narrow-gauge roads.

Italy has generally introduced the standard gauge of 1.445 m., the same as France, but uses also gauges of 0.95, 0.85, 0.8 m., and of 0.75 m. for the secondary railroad Agropoli-Niercato-Cilezito (Salerno). The first railway was opened in 1839. The industrial railroads and steam-tramroads have gauges of 0.70, 0.95, 1.0, 1.1 and 1.5 m. besides the prevailing standard gauge. The St. Léon Railway in Sardinia was given the gauge of 0.76 m. in 1865; besides this, the gauges of 0.85 and 0.95 m. are found. The narrow-gauge Sicilian railroads use the 0.95-m.

* Chemin de fer intérêt local de Neuilly à Beaumont, Sartiaux, 1874.

† Dr. Röll's Encyclopädie d. ges. Eisenbahnwesens, IV Band, 1892.

gauge. The Secretary of Public Works, Finali, declared, in 1891, in introducing a law for secondary railways into Congress, that the above "*enquête*" had unqualifiedly given as its opinion, that the 1-m. gauge had to be considered an extreme upper limit for secondary railroads.

In Belgium the first railroad was opened for public traffic in 1835. Standard gauge predominates, but the 1-m. gauge has been adopted for the local railroads, except those joining Dutch secondary railroads with a 1.067-m. gauge and the railway from Antwerp to Ghent, with a gauge of 1.150 m.

In Germany the first railroad, from Nürnberg to Fürth in 1835, and the Leipzig-Dresden Railway, were built at once to normal gauge, which has since been adopted for all German main railroads. The Mannheim-Basel Railway in Baden used alone the Irish gauge of 5½ ft. (1.60 m.), but altered it to standard gauge from urgent considerations of traffic; this was done from 1854 to 1855. The first railroad with all the characteristics of a secondary road in its construction and operation was the Bröhlthal Railroad in the Rhine province, 33.6 km., built in 1862, with a gauge of 0.785 m. It was followed by the Gerhard Prinz Wilhelm coal railroad, 4 km., 0.725-m. gauge, opened in 1863, and by the Ocholt-Westerstede Railway in Oldenburg, 0.750-m. gauge. In 1878, the agricultural railroads were introduced with 1-m. gauge.

It was reserved for the Secretary of State, Baron von Könneritz, and for Privy Councillor von Köpke to build narrow-gauge (0.75 m.) roads in Saxony to a greater extent, in a length of 199.36 km. Most recently, also, other German States show a movement in favor of the gauges of 0.75 and 0.60 m. Besides these gauges, those of 1.00, 0.90 and 0.785 m. are used by secondary railroads, and the gauges of 1.00, 0.95, 0.90, 0.85, 0.79, 0.785, 0.78, 0.75, 0.73, 0.70, 0.68, 0.66, 0.65, 0.60, 0.58 and 0.54 m. are found in use on mining, industrial, agricultural and forestry railways. The German Railway Union has recommended the gauges of 1.00 and 0.74 m. for narrow-gauge roads in establishing the principles for the construction and operation of local railroads, and in the code of rules for German railways of minor importance. Exceptions are admissible only with authorization of the Government, under concurrence of the Imperial Railway Commission. Especial mention should be made of the Prussian law of July, 1892, for "Small Railroads" and private feeders and the issue of specifications of November

1892, which permit only the gauges of 1.00, 0.75 and 0.60 m. besides the standard gauge for all railroads operated by engines.

In Schleswig-Holstein the main lines use standard gauge, the secondary roads have 1.00 and 0.88 m. gauge.

In Austria, the charter for the first railroad, from Linz to Budweis, was granted in 1824. It was opened partly September 30th, 1828; was completed August 1st, 1832; and was originally operated by horses. This line was followed by the Linz-Gmünden Railroad, opened May 1st, 1836; its division, Lambach-Gmünden, was changed for operation by locomotives in 1854; while the Linz-Lambach division was abandoned in 1859. The Lambach-Gmünden Railroad was therefore the first narrow-gauge road with a gauge of 3 ft. 7½ ins. (1.106 m.).

Later roads were all built to standard gauge, and only the Bosnian campaign opened a larger field to the 0.76-m. gauge and brought it into use for main lines, thanks to the War Department and to the Secretary of the Treasury, von Kállay. At present, in Bosnia and in the Herzegovina, the Doberlin-Banjaluka Railroad, 101.5 km., constructed by the Turkish government, and the junction road from Bosnian to Slavonian Brood, are built to standard gauge; the Bosna Railroad and the Bosnian-Herzegovinian State Railroad, with their adjoining transportation and industrial roads, in an aggregate length of 435 km., use the 0.76-m. gauge. Gauges of 0.550, 0.700 and 0.865 m. are also in use on transport and mining railways.

In 1888–89 charters were given to the following local railroads: the Mori-Arco-Riva Railroad, the Salzkammergut Railroad and the Steyrthal Railroad; they have a gauge of 0.76 m. and are now being successfully operated. The Styrian State local railroads, 0.76-m. gauge, were granted charters in 1890–91 and are now partly under construction, partly in operation. Other local railroads have been built with 1.0-m. and standard gauge.

In Hungary the principal roads have been built to standard gauge; for local railroads, the gauges of 1.00, 0.95, 0.80, 0.79, 0.76 and 0.75 m. are used besides standard gauge, the smaller gauges being mainly taken for coal and mining roads. The first 0.60-m. gauge road was the private cattle railroad from Berzowa to Lalasincze, 3.5 km., built in 1886.

Russia uses (the standard-gauge roads west of the Vistula excepted) a gauge of 1.524 m., which is at variance with all other great

European railway systems; this is also due to chance. The builder of the first Russian railway, from St. Petersburg to Zarskoe-Selo, the Austrian professor, Franz Anton Ritter von Gerstner*, in 1837, chose the gauge of 1.820 m., so as to construct powerful locomotives, oscillating little at high speeds, and to obtain a more favorable proportion between effective and dead load. The American engineer, Major Whistler, called as expert consulting engineer for later Russian railways, selected, however, the gauge of 5 ft. (1.524 m.), and this has remained the Russian gauge, and has also been adopted for the railways of Finland. On some roads of minor importance the 3 ft.-6 in. gauge (1.067 m.) has been introduced, and for feeders of main lines, over which the rolling stock of the latter cannot pass, the standards of the Russian government, June, 1892, fix a gauge of 1 ft. $11\frac{5}{8}$ ins. (0.60 m.).

Holland had adopted standard gauge for the Amsterdam-Haarlem Railroad in 1839; later, the broad gauge of 1.93 m. was originated on the Amsterdam-Hague-Rotterdam Railroad from causes not evident, but it has been removed since. Besides standard gauge, the gauges of 0.750, 1, 1.067 and 1.750 m., are in use on local and street railroads (*lokaal spoorwegen*).

On the Dutch dependency, Java, the first railroad from Samarang, built in 1862, uses standard gauge as the exception only. The other railroads of Java have a 3 ft.-6 in. gauge (1.067 m.), which is there considered as "standard gauge."

Luxemburg uses standard and 1-m. gauge.

Switzerland has adopted standard gauge and opened its first railroad in 1844; on the mountain (rack and cable) and on tramcar roads, the gauges of 0.75, 0.80 and 1 m. are predominant.

Spain uses the standard gauge on a majority of its roads, but there still exists the Spanish gauge of 5 ft. 6 ins. (1.776 m.), called "wide" or "broad" gauge, in contradistinction to narrow and standard gauge. Very recently, narrow-gauge roads have been built with 1-m. gauge. The first railroad was constructed in 1844.

Portugal opened the first railroad for public traffic in 1854 with a gauge of 5 ft. 6 ins. (1.676 m.). Later, roads were built also with gauges of 1 and 0.90 m.

In Scandinavia, narrow gauge has found entrance on some principal railroads and is preponderating.

* Dr. Röll's Encycl. d. ges. Eisenbahnwesens, IV Band, 1892, Biographie Gerstner.

In Sweden and in Norway the first railways were opened in 1851 and in 1854 respectively. In Sweden, standard and 0.891-m. gauges have been generally used; besides these, gauges are found of 0.802, 1.067, 1.093, 1.188 and 1.217 m. During the last years, more than 300 miles of secondary roads of 0.6-m. gauge have been built on the system of Civil Engineer A. F. Hummel.*

Greece has been one of the later European States in railroad construction. Its first line, Athens to Piräus, opened in 1869, was standard gauge. For the Thessalian railway system and for the Attic Railroad, though main traffic routes, 1.0-m. gauge has been selected for economic reasons; these roads are partly under construction, partly projected only. The line from Diakophto to Kalarryta has 0.75-m. gauge.

Denmark uses standard gauge; its first road was opened in 1847.

Roumania opened the first line in 1870 and has standard gauge exclusively.

Servia has been one of the last countries to undertake the building of railways; it has adopted standard gauge, the first line having been opened in 1884.

Bulgaria. First railway was opened in 1866; all roads are built to standard gauge.

European Turkey completed its first railroad in 1860 and has adopted standard gauge.

The first railroads built in the United States of North America, in 1827, and in Canada, in 1840, had taken standard gauge, because the first locomotives were brought over from England. When, however, Brunel and his partisans called attention to the advantages of a broader gauge regarding an easier construction of the engines and a greater stability of the trains, standard gauge appeared to be too small, and the New York and Erie Railroad, the Canadian Trunk Line and the Ohio and Missisippi Railroad chose the 6-ft. (1.829-m.) gauge.†

Other roads also have used gauges of 5 ft. (1.525 m.), 4 ft. 8½ ins. (1.435 m.), 5 ft. 6 ins. (1.676 m.) and 4 ft. 10 ins. (1.473 m.), without going to the above extreme. Besides these, gauges of 1.449, 1.068,

* Wochenschr. d. öst. Ing. u. Arch. Ver., No. 2 und 3, 1891.

† The Grand Trunk Line, in Canada, in 1873, altered its system from broad to standard gauge in one day. A similar feat was performed by the Southern railroads of the United States, which changed their lines from a 1.525-m. gauge to 4 ft. 9 ins., almost identical with standard gauge. This alteration was perfected on a length of roads of 18 500 km. in the days from May 31st to June 2d, 1886.

0.915 and 0.763 m. exist. On the Southern roads the gauge of 5 ft. (1.525 m.) was predominant.

But the necessity of a uniform gauge soon became evident. Many roads were built to standard gauge, and finally a compromise gauge of 4 ft. 9 ins. (1.448 m.) was agreed upon for economic reasons. Extensive systems were altered to conform to it. This dimension does not tally exactly with standard gauge, but the small difference is not considered an obstacle to through traffic.

After standard gauge had superseded broad gauge in the United States, it began the contest for superiority with narrow gauge. In 1871 the report of the legislative committee recommended the latter in the following words: "Where industrial railroads alone are possible, the adoption of narrow gauge permits the outlay to be cut down about one-half, without decreasing the requisite efficiency."

R. F. Fairlie* declared before the British Railway Union in Liverpool in 1870: "Every inch added to the absolutely necessary width of the gauge increases the cost of construction, the proportion of dead load and the cost of passenger traffic. It conseqently necessitates a higher tariff and diminishes the benefits of the road."

It must, however, be said that recently, since the introduction of trucks into the rolling stock, a movement in the opposite direction makes itself felt. The trucks allow curves to be passed, even of 27-m. radius without difficulty, as on the Manhattan Elevated Railroad in New York, and thus remove a principal argument in favor of the narrow gauge, viz., that it accommodated itself more easily to the formation of the country.†

Memorable is the 0.25-m. gauge of the line from Bedford, Mass., to North Billerica, 14 km. long.

In the Argentine Republic the first railroad was opened in 1857, in Chile in 1852, and in Peru in 1851; these roads were standard gauge and gauges of 5 ft. 6 ins. (1.676 m.), 1 m. and 0.763 m.

In Bolivia, the first railway was opened in 1873; the line from Antofagasta to Uyuni, 615 km., has been built to 0.76-m. gauge.

The first Brazilian railroads, completed in 1854, have a 5 ft.-3 in. gauge. Most roads use 1-m. gauge, however, which has also been taken for the Transandine Railway. Gauges of 1.40, 1.20, 0.95 and 0.60 m. are also in use.

* Dr. Röll's Encycl. d. ges. Eisenbahnwesens, III Band, 1891, und IV Band, 1892.
† Annales des Ponts et Chaussées, Août, 1892. Uniformité de largeur des voies ferrées aux États-Unis, par H. Rousseau.

In Venezuela, a 0.92-m. gauge has been built recently.

In Asia, the first railroads were built in the East Indies in 1853 with a 5 ft.-6 in. (1.676 m.) gauge, recommended by Simms. This gauge is called "Indian broad gauge" and is still prevalent. There are other roads with gauges of 4 ft. (1.219 m.), 3 ft. $3\frac{3}{8}$ ins. (1 m.), 2 ft. 6 ins. (0.762 m.), and 2 ft. (0.610 m.); the last on the line from Illigori to Darjeeling. The gauges of 4 ft., 2 ft. 6 ins. and 2 ft. were chosen in each case for special reasons, and therefore need not be taken into consideration, so that only the 1.676 and 1 m. gauges remain as representative. The Indian government seems, however, to favor the broader gauge, which is to be used in building the system of the Bengal-Nagpur Railway, the Madras-Calcutta Railway, the line from Kurrachee to Delhi, and the strategic railroad to Afghanistan and to Beloochistan.

In Asiatic Turkey the Ardin and the Cassaba Railroads, the line from Mersina to Adana and the Anatolian railways have been constructed with standard gauge. For the Jaffa-Jerusalem Railroad the 1-m. gauge has been chosen, which will also be used on the proposed lines Mudassia-Brussa and Saint Jean d'Acre-Damascus.

The first railroad in China, 8 km., built by the English from Shanghai to Kangwan, was given a 2 ft.-6 in. (0.76-m.) gauge. The same is used on numerous mining roads in Peru, leading from the interior to the ports.

In Japan, the first railroad was constructed in 1872, and there are at present about 3 000 km. of railroads, all with a 3 ft.-6 in. gauge.

In Africa, the first road was built in Egypt, in 1856, with standard gauge. Gauges of 5 ft. 6 ins. (1.676 m.) and 3 ft. $3\frac{3}{8}$ ins. (1 m.) are also in operation. The narrow-gauge road from Port Said to Ismaila, built by the Suez Canal Company, to join the Egyptian main line at Ismaila, has a 0.750-m. gauge. It will be opened shortly for passenger, baggage and express freight traffic; other freight is excluded. The Congo Railroad will also have the 0.760-m. gauge.

In Australia, we find three different gauges: 4 ft. $8\frac{1}{2}$ ins. (1.435 m.) in New South Wales; 5 ft. 3 ins. in Victoria and partly in South Australia (railroads opened in 1854); 3 ft. 6 ins. (1.067 m.) in Queensland, opened in 1865; in New Zealand in 1863; in West Australia and partly in South Australia, opened in 1854. Among them, the 4 ft.-$8\frac{1}{2}$ in. gauge is predominant.

It cannot be doubted, however, that the disadvantages resulting from the difference in gauges for international traffic and military purposes will lead also in that country to the adoption of a uniform gauge.

Total Length of Operated Railroads and Amount of Invested Capital.—At the close of 1890, the total length of railroads in operation on the earth, according to the statistics, was 617 265 km. They are divided between the continents as follows:

America	331 417 km.	= 54%
Europe	223 869 "	= 36%
Asia	33 724 "	= 5.5%
Australia	18 869 "	= 3%
Africa	9 386 "	= 1.5%

On these roads—

Standard gauge is used by	74%
Broad " "	12%
Narrow " "	14%

The total capital invested in railroads was, at the end of 1890, 131 000 million marks, or an average of 212 100 marks per kilometer.

Beginning of the Movement in Favor of Narrow Gauge.—The movement in favor of narrow gauge began in reality only in 1869, after attention had been called to the great importance and value of narrow-gauge roads at the meeting of German architects and engineers in 1868. Until then, main lines had been built almost exclusively; these had to carry a large traffic and had to be constructed as perfectly as possible. Only towards the end of the eighties the building of roads of inferior importance was begun on a larger scale, to accommodate minor traffic. On these roads, called "railroads of second order," it became possible to materially reduce the requirements of main lines regarding construction and operation. But even the relief accorded to these roads of "second order" did not suffice to make them interest-bearing. The outlay for construction and operation is still too high and generally renders their earning capacity entirely insufficient.

Necessity for the Introduction of Secondary Railroads with Simple Construction and Cheap Operation.—It has become necessary to develop a still more simple mode of construction for these railroads and for their

* Archiv f. Eisenbahnw., 3. Heft, 1892.

rolling stock, and to adopt a less elaborate system of operation, in order to best meet possible local demands and to assist the different branches of industry. The object has been attained generally only by introducing narrow-gauge roads (local, secondary, vicinal* railroads), which may be classified as "railroads of the third order." Determining principles for such roads are the following: economical construction; the utmost flexibility and freedom in the arranging of tariffs; a curtailment of the jurisdiction of the Government as to public interests, especially regarding regulations of safety and precaution, as well as a simple system of operation and greatest possible independence. At the head of such enterprises must be placed men of purpose and experience, well acquainted with the economic and commercial condition of the districts in question, and in close touch with the people interested in the roads, which must be adapted as closely as possible to the requirements of local traffic. The above data and deductions show what a chaos still exists in the dimensions of the gauge, and prove how important it would be, especially for narrow-gauge roads, to agree on certain definite gauges.

Based on the existence of such a necessity, the writer will now proceed to the discussion of the question at issue, of the advantages and disadvantages of the narrow gauges, as its proper selection must be considered as a fundamental condition for economy in constructing and operating railroads of minor importance.

Advantages of Narrow-Gauge Roads in General.—Authorities, who for many years have occupied themselves with the construction and operation of narrow-gauge roads, regard as their advantages:

I.—Savings in construction.

II.—Savings in the purchase of rolling stock.

III.—Savings in operation.

Disadvantages of Narrow-Gauge Roads in General.—On the other side, some not entirely unprejudiced experts consider as supposed disadvantages, or at least as objections:

I.—That the secondary roads are of smaller capacity, able to accommodate only a light and limited traffic, and consequently of little value for the purposes of the War Department.

II.—That their operation is comparatively dear, and that the transportation of animals is impossible.

* Railroads built on the vicinal roads (country highways).

III.—That the difference of gauge entails many inconveniences at the junction stations.

Arguments on Narrow-Gauge Roads from the Standpoint of the Requisite Capital and of the Quality of Traffic.—Before discussing the above advantages and disadvantages, the writer must emphasize that, in his estimation, the construction of a secondary road is a financial question primarily. The amount of the necessary capital is a function of the cost of construction and operation, and these again depend on the requirements of the passenger and freight traffic.

The narrow-gauge roads are means of transportation of inferior importance, which must bear proper relations to the demands made on them. The selection of the gauge will, therefore, depend not only on the requirements, but also on the extent and quality of the expected traffic, and, further, on the capital obtainable, with especial consideration of the earning capacity of the proposed railroad line and of all local conditions. The narrow-gauge roads have consequently found entrance everywhere, where the conditions necessary for the building and operating of standard-gauge roads do not exist.

Justification of the Hitherto-Used Gauges.—Each of the gauges used hitherto has its advantages, its disadvantages and its justification. Where a great bulk of freight is received from a standard-gauge road, and where the proposed line which is to join it is short, a standard-gauge road may be advantageous in a favorable locality and under certain conditions. In a difficult location, where heavy gradients or sharp curves cannot be avoided at all or only at great expense, the narrow gauge becomes the more preferable, as the object to be attained is to connect, at a small outlay and through simply operated roads, with the international traffic, parts of the country economically retarded or remote from the world's interchange; to facilitate their supply of raw material and the distribution of their products, and to create new industries. Such roads play the rôle of a truckman; they carry goods to the large roads and receive goods from them for delivery. It can be said that the gauge may be as variable as the necessity for the construction of secondary roads.

Consequently, the secondary roads must not adhere to the present system of construction and of equipment, and must deviate considerably from the standards of construction as well as of operation of large roads. They take the place of country roads or tramcar lines in a

measure, and deriving their principal importance from the accommodation of local traffic, the cost must bear a proper proportion to its demands, in order to insure a suitable percentage of interest to the invested capital.

Principal Conditions for Secondary Roads and for the Selection of their Gauge.—A cardinal principle must be to build secondary roads at the smallest possible expense, and a narrow gauge, light motors and low speed must be chosen to accomplish this. The last will permit an installation inadmissible with railroads using higher speed. The proper selection of the gauge is an essential condition, but we shall consider only the gauges of 1, 0.75 and 0.60 m., which have been principally and successfully used.

Advantages of Narrow-Gauge Roads in Detail.—Regarding the above-mentioned advantages of narrow-gauge roads, it must be stated—

I.—Economy in construction is principally brought about by the faculty of narrow-gauge roads to adapt themselves closely to the formation of the country and to use steeper gradients and smaller radii. The progress made already in this respect is proved by the fact that in some countries the cost per kilometer has been reduced from 100 000 francs to 30 000 francs, that is, to less than one-third.*

The cost per kilometer of Belgian narrow-gauge roads, on which 1.0-m. gauge prevails, fluctuates between 16 000 and 25 000 francs for substructure and superstructure, including bridges, culverts, etc.; they average 3 430 francs for buildings, making a total of 28 430 francs.

The 0.75-m. gauge Gelder road in Holland cost 32 400 francs per kilometer.

The average cost of the Saxon narrow-gauge roads, 0.75-m. gauge, has been 57 500 marks per kilometer.

In Germany, there are open for public traffic 1 051 km. of narrow-gauge roads with gauges of 1, 0.90, 0.785 and 0.60 m. Besides, there exist 4 198 km. of mining, industrial, agricultural, forestry and other roads, not open to the public, with gauges of 1, 0.95, 0.90, 0.85, 0.79, 0.785, 0.78, 0.75, 0.73, 0.70, 0.68, 0.66, 0.65, 0.60, 0.58 and 0.54 m. The average cost of the former was 52 124 marks per kilometer, the receipts, 4 721 marks, the running expenses, 3 210 marks, or 68.01% of the receipts. The capital brought an average interest of 2.6 per cent. The

* The average cost of secondary roads in France, with an aggregate length of 3 150 km. was 113 000 francs, at the end of 1890. Of this total length 1 450 km. were narrow-gauge roads, mostly with 1-m. gauge.

most expensive narrow-gauge road was one in the Breslau Railway district, with 95 114 marks per kilometer; the cheapest was the line Strassburg–Markolsheim with 15 179 marks per kilometer. The average cost of private feeders (1 124 km.), operated with engines, was 61 499 marks, and of those operated with horses (502 km.), 32 806 marks per kilometer.*

On standard-gauge roads the radius of curves must not be less than 100 m., or very serious disadvantages will have to be encountered; while with 1-m. gauge, radii down to 60 m., with 0.75-m. gauge down to 40 m., and with a 0.60-m. gauge down to 20 m. may be used. These curves permit the formation of the ground to be followed and result in savings in earth and rock work as well as in masonry and bridge work. The advantage of sharp curves and of steep grades makes itself especially felt where public country roads are utilized. On these the track can generally be laid on their grade and alignment, and can be carried through the villages to their mines or factories.

Hereby there are brought about :

(*a*) *Savings in the Roadbed.*—These are, especially if the railroad needs a separate roadbed, savings in the acquisition of right of way and in the amount of grading and of masonry and bridge work. The size of depots and yards can be reduced. The bottom width of roadbed for cuts and embankments in the open road is 4 to 4.30 m. for standard-gauge secondary roads; while, with the three most popular widths of narrow gauge, it can be built in the following dimensions :

Gauge.....	1 m.	0.75 m.	0.60 m.
Bottom widths of roadbed	3.3–3.5 †	2.0–3.0 ‡	2.6–2.8 §

If retaining walls are used in cuts or embankments, the bottom width of roadbed may be further diminished about 0.20 m.

* "Statistik d. im Betr. befindl. Eisenb. Deutschlands, Betriebsjahr 1890-91. Berlin, 1891."

† In Austria-Hungary (1-m. gauge).....3,0 m.
In Austria-Hungary—Bosnia and Herzegovina (0.76 m.).....2.8–3.0 "

‡ On the Saxon Secondary Roads (0.75 m.).....2.95 "
" " Ocholt-Westerstede Railroad, Germany (0.75 m.).....2.60 "
" " Bröhlthal Railroad, Germany (0.785 m.).....2.51 "
" " Waldenburg Railroad, Switzerland (0.75 m.).....2.83 "

§ On the Décauville railroads:
(France and transoceanic countries) (0.60 m.).....2.50 "
On the Scandinavian Local Railroads (0.60 m.).....2.80 "
" " line from Louisenhain to the Warthe in Germany (0.60 m.).....2.80 "

According to the experience on narrow-gauge roads in different countries, the average cost of the substructure stands about in the following proportions:

Gauge	1 m.	0.75 m.	1.60 m.
Ratio	1	0.92–0.90	0.88–0.80

(*b*) *Savings in Superstructure.*—The smaller gauge admits of a lighter superstructure on account of the use of rolling stock with less pressure per axle. The ensuing savings in the weight of rails and angle bars in wooden or iron ties or sleepers, in the amount of ballast, and, finally, in the number and length of yard side tracks, may be very considerable.

While on standard-gauge local railroads the weight of rail per running meter varies between 23 and 31 kg., it is—

With a gauge of	1 m.	0.75 m.	0.60 m.
Weight in kilograms per meter	18.0–26.0*	15.0–18.0†	9.0–15.0‡
Bottom width of roadbed (wooden ties) per meter	2.2–2.4	1.75–2.0	1.6–1.7
Thickness of same in meters	0.30	0.25	0.20

With iron ties the thickness of the ballast is still less and decreases down to 0.15 m. Wooden ties have lengths of 1.8, 1.5 and 1.3 m., an upper width of 14, 13 and 12 cm. respectively, and a thickness of 14 and 16 cm. The distance between centers of tracks at the stations is, according to the width of rolling stock, 3.5 to 3.75 m. with 1-m. gauge; 3.30 to 3.50 m. with 0.76 or 0.75 m. gauges; and 3 to 3.20 m. with a 0.69-m. gauge. The clearance between passing vehicles is generally made 0.70 to 0.80 m.

For the superstructure the following ratios may be therefore assumed as an average:

Gauge	1 m.	0.75 m.	0.60 m.
Ratio	1	0.8–0.7	0.6–0.5

	Weight of rail per meter.
* In Austria-Hungary (1-m. gauge)	17.8–23 kgr.
† In " " (0.76-m. ")	17.8–23 "
" Bosnia and the Herzegovina (0.76-m. gauge)	9.8–17.9 "
" Bosnia and the Herzegovina on rack railroads (0.76-m. gauge)	21.8 "
Saxon narrow-gauge roads (0.75-m. gauge)	15.5 "
Waldenburg railroad, Switzerland (0.75-m. gauge)	15.1 "
‡ Décauville railroads, France (0.60-m. gauge)	9.55–15 "
Scandinavian railroads (0.60-m. gauge)	9.9 "

Principal Dimensions of Recent Locomotives in

No.	Railroad.	Description.	Gauge.	Smallest admis-
			Meters.	
1....	S. Cristobal-Tucuman (The Argentine)	Tender-Locomotive, 3 axles coupled, weight empty, 13.6 tons (Cie. de Fives-Lille)	1.0	..
2....	Belgian Vicinal Railroads	Tender Locomotive, 3 axles coupled, weight empty, 18.5 tons (La Métallurgique)	1.0	..
3....	do	Tender-Locomotive, 3 axles coupled, weight empty, 15 tons (E. & J. Halot, Brussels)	1.0	..
4....	Innsbruck-Hall (Tyrol)	Tender-Locomotive, 2 axles coupled (Krauss & Co. Munich)	1.0	..
5....	do	" " "	1.0	..
6....	Jura-Simplon (Switzerland)	Tender-Locomotive for adhesion and rack railroad; 3 axles coupled, of which the central one is rack driving axle. Weight empty, 16.8 tons. (Winterthur, Switzerland)	1.0	..
7....	Appenzell Tramcar Railway (Switzerland)	Combined rack and adhesion engine, 2 coupled axles and rack working gear, tender and one "Bissel" axle (Syst. Klose). Weight empty, 26 tons. (Winterthur Mach. Co.)	1.0	30
8....	Salzkammergut and Styrian State Railways	Tender-Locomotive, 2 axles coupled. Weight empty, 9.5 tons. (Krauss & Co.)	0.76	..
9....	Salzkammergut, Steyrthal and Mori-Arco-Riva Railways	Tender-Locomotive, with combination pivot truck; 3 axles coupled, of which the near axle allows a lateral motion of 25 mm. each way. Adhesion weight, 18 tons. (Krauss & Co.)	0.76	30
10....	Bosna Railroad	Curve Locomotive, 3 axles coupled, which are movable radially, and one tender-axle (Syst. Klose). Adhesion weight, 20 tons	0.76	30
11....	do	Duplex-Locomotive (Syst. Fairlie). Weight empty, 19.2 tons. (Krauss & Co.)	0.76	30
12....	Herzegowinian Railroad, Maximum Grade 6 %	Combination Rack Railroad Locomotive (Syst. Abt). (Florisdorf Locomotive Works)	0.76	30
13....	Saxon Narrow-Gauge Railroads	Tender-Locomotive, 3 axles coupled. Weight empty, 12.45 tons. (Chemnitz Mach. Co.)	0.76	30
14....	do	Tender-Locomotive, with 2 boilers and 4 cylinders, twice 2 coupled axles and double furnace. Weight empty, 22.3 tons. (Syst. Fairlie.) (Glawthorn, Newcastle-upon-Tyne)	0.76	30
15....	Décauville Railroad (France)	Locomotive with 2 coupled axles and a tender with 2 axles. Weight empty, 5 tons. (Syst. Décauville)	0.60	15
16....	do	Locomotive with 2 coupled axles and a tender with 2 axles. Weight empty, 5 tons. (Syst. Decauville)	0.60	20
17....	Paris Exposition and French Military Railways	Compound Tender-Locomotive, all 4 axles coupled. Weight empty, 4.5 tons. (Syst. Mallett)	0.60	..
18....	do	Compound Tender-Locomotive, 2 pairs of coupled axles. Weight, empty, 9 tons	0.60	20
19....	do	Duplex Tender-Locomotive, 2 bogies and 1 furnace. Weight empty, 10.5 tons. (Syst. Péchot-Burdon)	0.60	20
20....	Décauville Railroad (France)	Combination Rack Railroad Locomotive. Weight empty, 13 tons. Etablissement Décauville)	0.60	{20 80

The Scandinavian Local Railways, 0.6 m. gauge, use compound locomotives with four cylinders and eight driving whee
Noticeable are the Legrand Compound Tender Locomotives for 0.6-m gauge, weight in service, 5.5 tons, 2 coupled axles,
and all the other mechanism remain unchanged.

There is further worth mentioning the Corpet and Décauville Tender-Locomotive, 0.6-m. gauge, for industrial and agric

TABLE "A."

OCOMOTIVES IN OPERATION ON NARROW-GAUGE RAILROADS WITH GAUGES OF 1.00, 0.75 or 0.7

	Gauge.	Smallest admissible radius.	Steam pressure in atmospheres.	Grate area.	Total heating surface.	Diameter of cylinder.	Stroke of piston.	Diameter of coupled wheels.	Weight when in service, in tons.	Average drawing capacity in kilograms.
	Meters.			Square Meters.		Meters.				
ives- ..... allur- ..... Halot, ... d, of tons. ..... rking tons. .. .. uss & ..... d, of esion ..... one ..... uss & ..... omo- ..... nnitz ..... axles Haw- ..... apty, ... apty, ... tons. ..... apty, ... 10.5 ..... Eta-	1.0	..	..	0.61	29.80	0.270	0.380	0.800	18.0	....
	1.0	..	..	0.77	34.30	0.350	0.360	0.832	22.8	....
	1.0	..	..	0.72	30.20	0.280	0.360	0.820	18.0	....
	1.0	..	15	0.29	12.84	0.180	0.300	0.750	7.8	970
	1.0	..	15	0.35	18.26	0.225	0.300	0.750	10.6	1 060
	1.0	..	15	0.98	54.7	0.330	0.480	{ 0.796 / T 0.806 }	21.4	....
	1.0	30	12	1.40	94.0	0.360	0.400	{ * 0.800 / ** 0.860 }	32.5	....
	0.76	..	12	0.43	23.48	0.225	0.350	0.75	12.0	1 400
	0.76	30	12	0.8-1.0	43-50	0.290	0.400	{ 0.550 / T 0.800 }	22.7-24	2 500
	0.76	30	12	0.90	58.82	0.290	0.450	0.900	25.0	2 520
	0.76	30	12	1.0*	58.4	0.240	0.300	T 0.750	24.2*	2 430
	0.76	30	12	1.20	70.00	{ * 0.340 / ** 0.300 }	{ * 0.450 / ** 0.360 }	{ * 0.800 / ** 0.688 }	31.0	{ * 4 000 / ** 2 830
	0.76	30	12	0.66	29.27	0.240	0.380	0.750	16.0	2 100
	0.76	30	10	1.16	57.78	0.216	0.335	0.813	28.0	2 420
	0.60	15	9	0.29	8.71	0.150	0.300	0.60	6.25	722
	0.60	20	9	0.30	15.0	0.210	0.300	0.70	7.50	1 020
	0.60	..	12	0.42	22.3	{ V 0.170 / H 0.225 }	0.255	0.60	12.0	2 155
	0.60	20	12	0.50	22.3	{ V 0.187 / H 0.280 }	0.300	0.60	12.0	1 800
	0.60	20	12	0.48	25.6	0.175	0.240	0.63	13.0	1 900
	0.60	{ 20 * / 80** }	12	....	27.0	0.250	0.360	0.72	16.0	....

eight driving wheels which are able to draw a 40-ton train at a speed of 24 km. per hour on gradients of 2.86%, and
us, 2 coupled axles, which can be also used for 1-m. gauge. To do this, the axles are taken out, the wheels are put out

ndustrial and agricultural purposes. *Vide* "La Locomotive à voie étroite à l'Exposition de 1889," Génie civil, 1890, "

NOTES.

On exhibition at the Paris Exposition, 1889.
Vide Organ f. d. Fortschr. d. E. Bw., 1891. Uebersicht der in Paris ausgestellten Loc. H. v. Littrow. Stahl u. Eisen, 1892. Ueber Feldeisenbahnen, E. A. Ziffer.

Information from the Locomotive Works of Krauss & Co., Munich and Linz.

Monographie d'un chemin de fer routier à voie de 1 m, à adhérence et à crémaillère, J. Martin et L. Marad. Paris, 1891. Nouvelles Annales de la Constr. Décembre, 1891.
* Adhésion } Mechanism.
** Rack }
Diameter of Tender Wheel, 0.555 m.
Information from Krauss & Co.

Trial runs made with a maximum speed of 35 km. per hour.

Glaser's Annalen, 1838: Trial runs with 50 km. speed.
Construction of two coupled locomotives, touching with their fireboxes; the two engines can be used separately.
* Weight, empty and in service, grate and heating surface given for both engines.
* Adhesion } Mechanism.
** Rack }

Vide Secondary Railways of Saxony. Berlin.

do

Vide Const. et exploitation des chemins de fer à voie de 0.6 m. R. Tartary, Paris, 1891.
Vide Const. et exploitation des chemins de fer à voie de 0.6 m. R. Tartary Paris, 1891.

A. Mallet: Développement de l'application du système compound aux machines locomotives. Paris, 1890.
Schweiz. Bauzeitung, 1890.

Information from the Décauville Company.
* 20 m. Adhesion } Railroads.
** 80 m. Rack }
The engine may reach a weight of 21 tons.
The trains on the railroads of the Departments Loiret and Calvados, on the Royan tramcar line and on the Escoublac-la-Bôle Pornichet Railroad, run with a speed of 25 to 30 km. per hour.

which pass curves of 20 m. radius.
side of the frame and the crank pins are keyed on to them; the journal boxes

Ueber Feldeisenbahnen," E. A. Ziffer, Stahl und Eisen, 1892.

(c) *Savings in Buildings.*—These savings can become very large if a railroad limits itself to provisional and absolutely necessary structures, which may be done especially on roads with smaller gauge accommodating a limited traffic. But savings in the depots are possible in every case.

II. *Saving in Equipment.*—The smaller the gauge, the less becomes the weight of the rolling stock, without necessarily diminishing its stability or effectiveness in equal proportion. Unquestionably, the cost of the equipment, built lighter for a lighter traffic, diminishes also with the gauge, even under the same requirements concerning carrying capacity and appliances of safety and precaution (brakes, drawing gear, buffers, etc.).

Table "A" of "Principal Dimensions of Locomotives," shows that the engines for a smaller gauge (0.86 or 0.75 m.) have been constructed with a larger grate area and a greater drawing capacity than those for 1-m. gauge; further, that engines for 0.6-m. gauge are capable of meeting very stringent demands, especially as to drawing capacity, adhesion, weight and flexibility in passing sharp curves. Combined rack railroad locomotives for a 0.76-m. gauge have also been long in operation without giving any trouble or being less safe.*

The construction of modern locomotives is certainly suitable to facilitate the building of railroads at a small outlay and to guarantee the earning capacity of lines, very doubtful at a greater cost. We find, also, that all hindrances to narrow gauge have been removed as to the effectiveness of locomotives.†

‡Table "B" of "Covered and Open Freight Cars" shows that cars with a loading capacity of 10 tons can be built, not only for 1-m. gauge, but also for smaller gauges, in which case the dead weight per ton of capacity, available area and volume of cars is lessened.

§Table "C" gives the main dimensions of passenger cars, which show also a more favorable proportion between gauge and width of cars. The cars for the Salzkammergut and the Styrian Local Railroads (0.76-m. gauge) are 2.2 m. wide, those of Décauville (0.60 m.) are 1.7 m., that is, almost three times as wide as the gauge, and have been in unobjectionable use for an extended period. The cars of the Bosna

* In the Décauville shops the writer saw a combined (adhesion and rack) locomotive for 0.60 m. gauge, the dimensions of which are also contained in "Table A."

† "Ueber die Secundärbahnen in Frankreich," E. A. Ziffer, Zeitschr. f. Eisenb. u. Dampfschiffahrt, Mai, 1891. Zeitschr. f. Transportw. u. Strassenbau, No. 24, bis 30, 1892.

‡ See pp. 18–20.

§ See pp. 22, 23.

TABLE B.

PRINCIPAL DIMENSIONS, WEIGHT, CAPACITY, ETC., OF RECENT FREIGHT CARS, IN OPERATION ON NARROW-GAUGE RAILROADS WITH GAUGES OF 1, 0.75 OR 0.76 AND 0.6 M.

Number.	Railroad.	Gauge in Meters.	Number of Axles. Distance c. c. in Meters.	Body of Car. Length.	Body of Car. Width.	Body of Car. Height Above Rail.	Own Weight.	Capacity.	Ratio of Own Weight to Capacity.	Dead Weight per Ton of Capacity in Kilograms. Box.	Dead Weight per Ton of Capacity in Kilograms. Gondola.	Dead Weight per Ton of Capacity in Kilograms. Platform.	Available Area for Loading.	Available Volume for Loading.	Notes.
				Meters.			Tons.			Average Car.			Sq. M.	Cu.M	
1..	Belgian Vicinal Rys	1.0	.....	.....	.....	.....	.....	10.0	.....	.....	400	.....	.....	.....	Bull. de la Comm. Internat. du Cong. des chems de fer, Mars, 1892.
2..	do	1.0	.....	.....	.....	.....	.....	5.0	.....	.....	540	.....	.....	.....	
3..	Économ'ques du Nord (France)	1.0	.....	.....	.....	.....	.....	10.0	.....	445	390	370	.....	.....	
4..	Sud de la France (Var et littoral)	1.0	.....	.....	.....	.....	.....	10.0	.....	550	450	350	.....	.....	
5..	Circum-Etna (Sicily)	1.0	.....	.....	.....	.....	.....	7.5	.....	400	375	312	.....	.....	
6..	Skagens Railway (Denmark)	1.0	2 / 3.6	4 0	1.80	1.9	2.04 / 2.23	5.0	1:2.45 / 1:2.24	408 / 446	.....	.....	7.2	13.68	"Die Skagensbahn" Kuhrt. Z f. Loc. u. Strass.Bw.,1891.
7..	do	1.0	2 / 2.5	3.97	1.84	0.7	2.20	5.0	1:2.27	.....	440	.....	7.2	5.04	
8.	Filder Ry. (Stuttgart-Degerloch)	1.0	2 / 2.8	6.07	2.37	.....	3.23	8.0	1:2.47	.....	.....	404	.....	.....	Z. f. Loc. u. Strass. Bw., 1886.
9..	County Ry, Flensburg-Kappeln (Schleswig)	1.0	2 / 2.7	6.05	2.15	2.91	5.37	5.0	1.0.93	1074	.....	.....	13.0	27.3	Die schmalspur. Kreiseisenb. Flensburg-Kappeln. Kuhrt. Z f. L u. Str. Bw ,1886.
10..	do	1.0	2 / 2.3	4.3	2.15	2.89	3.31	5.0	1.1.51	662	552	.....	9.24	20.3	
11..	do	1.0	2 / 2.3	4.5	2.15	1.55	2.76	5.0	1:1.81	.....	.....	500	9.67	7.73	
12..	do	1.0	2 / 2.3	4.5	2.15	.....	2.50	5.0	1.2	.....	.....	.....	9.67	.....	

13..	Eichstadt-Stadt, Eichstadt (Bavaria)	1.0	.....	5.4	2.5	2.93	3.4 4.0	7.5	1:2.21 1:1.87	405 533	.....	.....	13.5	29.7	Z. f. Loc. u. Strass. Bw., 1886.
14..	do	1.0	.....	5.4	2.5	1.94	3.2	7.5	1:2.34	.....	426	.....	13.5	16.2	
15..	Felda Ry. (Sachsen-Weimar)	1.0	2 2.3	4.45	2.1	2.9	2.5	5.0	1:2	.....	.....	500	9.34	20.08	
16..	do	1.0	2 2.7	5.93	2.15	1 36	3.2 2.3	7.5	1:2.58 1:2.34	.....	387 426	.....	12.75	7.65	Z. f. Loc u. Strass. Bw., 1885.
17..	Innsbruck-Hall (Tyrol)	1.0	2 1.8	5.0	2.1	3.0	2.85	5.0	1:1.75	570	.....	.....	10.5	23.1	
18..	Lugano Lake Narrow-Gauge Ry. (Switzerland)	0.8	4 5 0	7.5	.....	.....	4.5	10.0	1:2.22	.....	.....	.....	.....	.....	Z. f. Loc. u. Strass. Bw., 1886.
19..	I. R Bosnn. and Bosnian-Herzegowinian State Ry	0.76	2 2.7	5.00 4.50	1.80	2.27	3.0 3.2	6.0	1:2 1:1.87	378 533	.....	.....	9.0 8.1	.....	The freight cars with two axles have room for 20 soldiers; those with three axles for 30 soldiers or four horses; all axles are radially movable (Syst. Klose).
20..	do	0.76	3 5.0	7.30 6.80	1.80	2.27	5.1 5.6	10.0	1:1.96 1:1.78	510 560	.....	.....	13.14 8.84	.....	
21..	do	0.76	2 2.7	5.0	1.90	0.9	2.4 2.6	6.0	1:2.5 1:2.30	.....	400 433	.....	9.5	8.55	
22..	do	0.76	3 5.0	7.3	1.90	1.0	4.3 4.8	10.0	1:2.32 1:2.08	.....	430 480	.....	13.87	13.87	
23..	do	0.76	2 2.7	5.0	1.90	0.6	2 4 2.6	6.0	1:2.50 1:2.30	.....	.....	400 433	9.50	5.70	
24..	Mori-Riva-Arco (Tyrol)	0.76	2 3.7	6.0	1.85	2.87	3.5	5.0	1:1.43	700	.....	.....	11.10	24.42	
25..	do	0.76	2 3.7	6.0	2.0	1.0	2.8	5.0	1:1.78	.....	560	.....	12.0	12.0	Coal cars with brakes.
26..	do	0.76	2 3.7	6.0	2.0	.....	2.7	5.0	1:1.85	.....	.....	540	12.0	2.93	
27..	Salzkammergut Ry. and Styrian State Rys	0.76	2 3.7	6.3	1.97	2.89	3.45	5.0	1:1.44	690	.....	.....	12.41	27.30	Box cars with brakes.
28..	do	0.76	2 3.7	6 3	2.0	1.61	3.05	5.0	1:1.64	.....	.....	610	12.6	12.6	With brakes.
29..	Steyr Valley Ry. (Upper Austria)	0.76	2 3.8	6.0	2.0	2.85	3.8	6.0	1:1.57	633	.....	.....	8.82	18.0	
30..	do	0.76	2 3.8	6.0	1.86	1.57	2.9	6.0	1:2.07	.....	483	.....	11.10	10.0	
31..	do	0.76	2 3.8	6.0	1.86	0.975	2.7	6.0	1:2.20	.....	.....	450	11.10	2.5	
32..	Bari-Barletta (Italy)	0.75	.....	.....	.....	.....	.....	6.0	.....	450	391	408	.....	.....	Bull. de la Comm. Internat. du Cong. d. ch. d. fer, Mars, 1892.
33..	Saxon Narrow-Gauge Rys	0.75	2 2.7	4.1	1.7	2.57	1.925 2.100	5.0	1:1.92	385 420	.....	.....	6.97	13.9	"Die neuesten Schm. spurb. in Sachs." Dickmann. Z. f. L. u. Str. Bw. 1885 u. 1887. Civil Ingenieur, 1885.
34..	do	0.75	2 3.8	5.8	1.6	1.55	2.023 2.21	5.0	1:2 46 1:2.27	.....	405 440	.....	9.28	4.176	
35..	do	0.75	2	4.1	1.75	2.5	2.10	5.0	1:2.38	.....	.....	420	7.17	7.6	

TABLE B—(*Continued*).

Number.	Railroad.	Gauge in Meters.	Number of Axles. Distance c. c. in Meters.	Body of Car.			Own Weight.	Capacity.	Ratio of Own Weight to Capacity.	Dead Weight per Ton of Capacity in Kilograms.			Available Area for Loading.	Available Volume for Loading.	Notes.
				Length.	Width.	Height Above Rail.				Box.	Gondola.	Platform.			
				Meters.			Tons.			Average Car.			M^2	M^3	
36.	Mannsfeld Narrow-Gauge Rys. (Prussia)	0.75	2	5.05	1.65	.....	2.80 3.0	5.0	1:1.78 1:1.66	.....	560 600	.....	8.33	9.16	Z. f. d. ges. L. u. Str. Bw., 1885.
37..	do	0.75	2	4.56	1.0	.....	2.25 2.45	6.0	1:2.66 1:2.45	.....	.....	375 408	4.56	2.28	
38..	Waldenburg Ry. (Switzerland)	0.75	2 2.0	4.03	1.75	2.86	2.480	5.0	1:2.02	496	.....	.....	7.05	15.50	"Die Waldenburger Bahn" Brodbeck Z. f. d. ges. L. u. Str.Bw.,1882.
39..	do	0.75	.....	4.03	1.75	2.8	2.05	5.0	1:2.44	401	.....	.....	7.05	15.50	
40..	do	0.75	.....	4.0	1.75	0.45	1.6	5.0	1:3.12	.....	302	.....	7.0	3.15	Constr.et exploit.des Ch. de fer à voie de 0,6 m. Tartary, Paris, 1891.
41..	Décauville Ry. (France)	0.6	2 1.5	3.5	1.62	1.70	0.9	3.0	1:3.33	300	.....	.....	5.67	10.94	
42..	do	0.6	2 1.5	4.0	1.70	1.89	1.2	5.0	1:4.16	240	.....	.....	6.80	13.60	Capacity not limited to 10 tons; there are cars with single loads of 18,36 and 48 tons, which weigh only 200 kg. per ton, capacity, *i. e.*, 20% of the load.
43..	do	0.6	4 3.5	6.0	1.70	2.41	2.7	10.0	1:3.70	270	.....	.....	10.2	19.38	
44..	do	0.6	4 3.5	6.0	1.70	2.41	3.7	10.0	1:2.70	370	.....	.....	10.2	19.38	
45..	do	0.6	4 3.6	6.0	1.70	1.25	2.7	10.0	1:3.70	.....	270	.....	10.2	7.14	

The freight cars of the Scandinavian railways of 0.6-m. gauge have a capacity of 5 tons; weight, 1 to 1.3 tons; distance c. c. axles, 2 m.; length of car body, 4 m.

A decree of the French Secretary of the Department of Public Works fixes the maximum clearance profile as follows:

1-m. gauge: Width of car, 2.8 m.; Height, 2.8 m.
0.75 m. " " " 2.5 m.; " 2.7 m.
0.6-m. " " " 2.2 m.; " 1.8 m.

In the columns, "Own Weight," and "Ratio of Own Weight to Capacity," the figures above the lines refer to cars without brakes, and the figures below the lines to such with brakes.

Railroad (Coupé system) give a clear width of 1.8 m., so as to admit of a recumbent position of the passengers. To facilitate the passing of curves, movable axles or trucks are, of course, used on narrow-gauge roads; the latter have been adopted for the Décauville cars, which may be considered as examples to be followed. Special mention should be made of the combined cars, length over all 9.8 m., inside length of box 5.95 m.; then those with an outside width of box of 1.7 m., and an inside width of 1.65 m., weight 4.7 tons, capacity four horses, four head of cattle or 24 men; finally, the covered box cars, volume 20 cu. m., capacity 10 tons, with floors so low that inclined platforms are dispensable for loading and unloading.

In comparing the dimensions of rolling stock given in the above three tables, their mode of construction has to be taken into consideration. The dead weights of cars depend also on the material, for which the writer has no data.

Total Savings in the Construction of Narrow-Gauge Roads.—Considering the savings in narrow-gauge roads in their entirety, the estimates of eminent engineers for certain railroads in different countries, for various gauges, always taking the greatest admissible grades and smallest radii, result in saving, according to the chosen gauge and the locality, 30 to 70% against standard gauge. With the difficulties of the locality, the saving by the use of narrow gauge increases. But these data can give directions only; special estimates must be made for each separate case, and the difference of cost has to be calculated for the different gauges.

III. *Savings in Operation.*—The working expenses comprise:

(*a.*) General administration.

(*b.*) Maintenance and inspection of roadbed.

(*c.*) Station and yard service.

(*d.*) Train and shop service.

Strictly speaking, the cost of the general administration and partly of the station and yard service is independent of the gauge; but the saving in maintaining and inspecting the roadbed is quite noticeable, as there is less substructure work, especially less and not so important masonry work, a lighter construction of superstructure and lower speed of trains. There are savings by the limited extent of buildings, and in the train and shop service, due to the less wear of rolling stock by its smaller dead load and more simple construction, and also to shorter trains and to the easier handling of them in the stations.

TABLE C.

PRINCIPAL DIMENSIONS AND WEIGHTS OF RECENT PASSENGER CARS IN OPERATION ON NARROW-GAUGE RAILROADS, WITH GAUGES OF 1, 0.75 OR 0.76 AND 0.60 M.

Number.	Railroad.	Gauge in Meters.	Number of Axles.	Distance c. c. Axles in Meters.	Class of Compartments.	Body of Car. Meters. Length.	Width.	Height.	Ratio of Gauge to Width of Car Body.	Seats. Number.	Length. Per Passenger in M.	Width.	Own Weight in Tons.	Dead Weight per Seat in Kg.	System.	Notes.
1..	Belgian Vicinal Railways	1.0	.....		II	.....	2.20	....	2.20	.....	0.50	0.42	.....	114	.....	Bull. de la Comm. Intern. du Congr. des chemins de fer, Mars, 1892.
2..	Chem. de fer écon. du (Nord) France	1.0	.....		II	.....	1.90	....	1.90	.....	0.45	0.45	.....	132	.....	
3..	Chem. de fer du Sud de la France (Centr. Var. et Littoral)	1.0	.....		I	.....	2.55	....	2.55	.....	0.51	0.50	.....	239	.....	
4..	Circum-Etna (Sicily)	1.0	.....		III	.....	2.32	....	2.32	.....	0.42	0.27	.....	132	.....	
5..	Skagens Ry. (Denmark)	1.0	.....		II & III	6.0	2.10	2.0	2.10	....	.....	.....	3.9	.....	Coupé car.	Z. f. d. ges. L. u. Str. Bw., 1891.
6..	Filder Ry. (Stuttgart-Degerloch)	1.0	2 4	.....		7.73	2.47	2.15	2.47	48	.....	.....	5.63	118	Intercom c.	Z. f. d. ges. L. u Str. Bw., 1886.
7..	do	1.0	2 2.3	.....		5.55	2.15	2.30	2.15	24	.....	.....	4.24	176	do	
8..	County Ry. Flensburg-Kappeln (Schleswig)	1.0	2 2.7	.....	II & III	5.97	2.20	2.18	2.20	24	.....	.....	5.30	220	do	Z. f. d. ges. L. & Str. Bw., 1886.
9..	Eichstadt-Stadt. Eichstadt (Bavaria)	1.0	.....	.....		5.77	2.5	2.95	2.5	32	.....	.....	5.00	156	.....	Standing room for 14 to 16 passengers.
10..	Felda Ry (Sachsen-Weimar)	1.0	2 2.3	.....	II & III	5.44	2.1	2.91	2.1	24	.....	.....	4.30	179	Intercom c.	Transverse seats. Z f. d. ges. L. u. Str. Bw., 1886.
11..	Innsbruck-Hall (Tyrol)	1.0	2 1.8	.....		3.6	2.1	1.88	2.1	16	0.55	0.45	2.65	153	do	Longitudinal seats.
12..	Lugano Lake Narrow-Gauge Ry. (Switzerland)	0.8	.....	.....	I & III	.....	.....	.....	.....	24 40	.....	.....	5.8 5.2	242 130	.....	Z. f. d. ges. L. u. Str. Bw. 1886.

13..	I. R. Bosna and Bosnian-Herzegowinian State Ry....	0.76	2 / 2.7	I & II	4.89	1.63	1.87	2.14	14	1.Cl. 0.9 / 2.Cl. 0.65	0.60	2.3	164	Coupé.	Transv'se seats.	Cars run very smoothly, even at a speed of 40 km. Axles are radially movable. System, Klose.
14..	do.....	0.76	3 / 5	I & II	7.24	1.79	2.40	2.37	22	1.Cl. 0.9 / 2.Cl. 0.65	0.60	7.0	318	do	do	
15..	do.....	0.76	2 / 2.7	III	4.36	1.78	2.05	2.36	15	0.45	0.45	3.6	240	do	do	
16..	do.....	0.76	3 / 5	III	6.74	1.79	2.40	2.37	24	0.45	0.45	6.9	287	do	do	
17..	do.....	0.76	2 / 2.7	IV	4.86	1.78	2.05	2.36	16	0.40	0.42	3.2	200	do	do	
18..	do.....	0.76	3 / 5	IV	7.24	1.79	2.15	2.37	30	0.40	0.42	6.1	200	do	do	
19..	Mori-Riva-Arco (Tyrol)	0.76	2 / 3.7	I	5.64	2.1	2.87	2.76	16	0.68	0.50	4.5	281	Intercom.	do	
20..	" "	0.76	2 / 3.7	I & III	5.64	2.1	2.87	2.76	24	1.C.0.50 / 3.C.0.475	0.50 / 0.475	4.15	173	do	do	Data of the car works of J. Weitzer, Graz.
21..	Salzkammergut Ry. and Styrian State Rys.	0.76	2 / 3.7	I	5.54	2.2	2.87	2.76	14	0.68	0.5	4.5	321	do	do	
22..	Salzkammergut Ry. and Styrian State Rys.....	0.76	2 / 3.7	II	5.54	2.2	2.87	2.89	21	0.49	0.5	4.1	195	do	do	
23..	do.....	0.76	2 / 3.7	II & III	5.54	2.2	2.87	2.89	24	0.47	0.45	4.1	171	do	do	
24..	do.....	0.76	2 / 3.7	III	5.54	2.2	2.87	2.89	24	0.475	0.475	4.5	168	do	do	
25..	Steyr Valley Ry. (Upper Austria.....	0.76	2 / 3.8	III	5.00	1.8	2.85	2.38	20	0.485	0.50	3.75	187	do	Longit. seats.	
26..	Bari-Barletta (Italy).....	0.75	.....	III	.....	1.9	....	2.63	.....	0.38	0.27	.....	96	.....	Bull. de la Comm. Intern. du Congr. de chem. de fer, Mars, 1892.	
27..	Saxon Narrow-Gauge Rys....	0.75	2 / 3.3	III	5.8	1.62	2.0	2.16	16	.....	.....	2.45	153	.....	Standing room for 6 pass., brake; sliding axles.	
28..	" "	0.75	4	II & III	10-62	1.62	2.0	2.16	33	.....	.....	4.75	143	.....	Sliding axles.	
29..	Mannsfeld Narrow-Gauge Rys. (Prussia).....	0.75	2 / 5	III	5.7	1.65	2.65	2.16	.....	.....	.....	3.6	.....	.....	Movable axles, Longit seats.	Z. f. d. ges. L. u. Str. Bw., 1885.
30..	do.....	0.75	4 / 5.3	.....	6.1	2.0	3.50	2.66	60	.....	.....	4.4	73	.....	For workingmen trains, with roof seats, longt. seats and bogie trucks.	
31..	Waldenburg Ry. (Switzerland)	0.75	2 / 2.35	II & III	5.5	1.75	2.84	2.33	21	.....	.....	3.1	147	.....	Standing room for 6 pass., transv'se seats.	Z. f. d. ges. L. u. Str. Bw., 1885.
32..	" " ..	0.75	2 / 2.35	II & III	5.5	1.75	2.84	2.33	18	.....	.....	2.5	138	.....	Standing room for 10 pass., lng. seats.	
33..	Décauville Ry. (France).....	0.60	2 / 1.4	I & II	3.8	1.70	2.33	2.83	12.16	.....	.....	1.05-1.35	87	.....	Constr. et exploit des chems. de fer à voie de 0.6 m. Tartary, Paris, 1891.	
34..	" "	0.60	2 / 1.4	III	3.6	1.70	2.33	2.83	16	.....	.....	1.35	83	.....		
35..	" "	0.60	4 / 6.5	III	9.0	1.70	2.41	2.83	56	.....	.....	4.5-6 5	80-116*	.....	*Dead w't can be reduced to 70 kg. on summer cars.	

All these savings in working expenses can be proved only by elaborating comparative studies on the systems of operation for different narrow gauges. Otherwise, the given differences can be regarded as only approximately correct.*

Disadvantages of Narrow-Gauge Roads in Detail.—The supposed disadvantages are :

I. Limited traffic, small efficiency and little usefulness for military transports. These objections are contradicted by actual experience. The writer will cite the following widely known examples :

1st. The single-track road, gauge 1 ft 11½ ins. (0.597 m.), from Festiniog to Port Madoc, in North Wales, built as a horse-car line in 1832, gradually rebuilt and operated by locomotives since 1864. It is 23 km. long and has 12 branches with the same gauge with a total length of 22 km., leading to the slate quarries of Galles. The original capital, 40 000 francs per kilometer, has been raised to 165 000 francs per kilometer by a series of transformations, and consists of stocks exclusively. The weight of rail has increased from 8 kg. per meter in 1832, successively to 15 kg. in 1847 and to 24 kg. in 1871. The maximum grade is 1.25%, the curves with radii of ordinarily 120 m. go down to radii of 35 m., used without tangents between reversed curves.

Traffic has continually increased since 1865; in the beginning, the number of passengers was 23 000 per annum; while in 1888, 142 000 persons and 113 000 tons of freight were carried, and this during the day only (no trains run on Sunday). There are 12 trains in each direction daily, of which six are passenger trains; the trains number often up to 150 cars, with an aggregate length of 360 to 400 m. The annual gross receipts per kilometer reached the sum of 29 000

* Die gemischte Spur. Jahrb. d. sächs. Ing. u. Arch. Ver., Köpke, 1883. Frankreich's Local u. Schmalspurb., W. v. Nördling. Zeitschr. f. d. ges. Local u. Strassenbahnw., 1886.

Ueber Schmalspurbahnen f. Pers. u. Güterverkehr. Mittheil. über derartige Bahnen in North Wales, spec. über die Festiniog Bahn, R. Koch, Z. f. d. ges. L. u. Str. Bw., 1881.

Betriebsresultate d. Schmalspurb., Bröhlthal, Felda. u. Waldenburgerbahn. Z. f. d. ges. L. u. Str. Bw., 1883–1891.

Die Zuider Dampftramway, W. Hostmann. Z. f. d. ges. Loc. u. Str. Bw., 1882.

Ueber schmalspurige Industrie Bahnen, Hostmann. Z. f. d. ges. Loc. u. Str. Bw. 1882.

Die Brünigbahn, O. Zschokke u. G. Ott, Z. f. d. ges. L. u. Str. Bw., 1882-83 u. 1886.

Ueber Schmalspurb., A. Birk. Z. d. öst. Ing. u. Arch. V., 1885.

Bau u. Betrieb d. Schmalspurb., Hostmann, Wiesbaden, 1881.

Vergleich. Betracht. über Bau u. Betriebsergebnisse normal u. schmalspuriger Secundärb. O. Schröter. Z. f. d. ges. L. u. Str. Bw., 1882.

Neuere Fortschritte d. Schmalspurb., A. Birk; Z. d. Ver deutcher Eisenbahnverw., Nos. 96–98, 1891.

francs, of which 8 000 francs are due to the passenger traffic.* The traffic is consequently four times as large as that of the Algerian railroads, and the yearly net receipts amount to nearly 34 000 francs, which income would authorize the French government to compel the Algerian roads to lay a second standard-gauge track.

2d. The Illigori Darjeeling Railway, in British India, 2-ft. (0.61-m.) gauge, on the road from Calcutta to the first plateau of the Himalaya, at an altitude of 2 000 m. above sea-level, is laid mostly along the highways with average grades of 2.5%, a maximum grade of 3.5% and curves with radii down to 21 m. Weight of rail, 21 kg. per meter. Cost, 78 000 francs per kilometer. In 1888, 42 800 passengers and 24 700 tons of freight were carried at gross receipts of 17 940 francs per kilometer. The running expenses were 54% of the receipts.

3d. The railroad from Antwerp to Ghent, in Belgium, gauge, 1.15 m., length, 50 km., built between 1844 and 1847, is operated similarly to trunk lines with through trains of 50 km. hourly speed. This road carried 500 000 passengers and 50 000 tons of freight in 1865; in 1887 the passengers numbered 1 089 838, and the receipts were 765 409 francs; 713 591 francs were received for baggage, express, and common freight. The expenses were 64.09% of the income.†

4th. The Paris Exposition Railroad on the Champ de Mars, in 1889, surnamed "Décauville Railroad," 3 km., 0.60-m. gauge, carried six and one-half millions of passengers within six months. This is double the rate of the Dépôt de la Bastille in Paris, which summed up only five and one-half millions in 12 months. Forty-two thousand five hundred trains were run, with a total weight of 1 781 018 tons, making 106 250 train-kilometers. Each train had a capacity of 400 travelers. The gross receipts per kilometer in six months were 550 000 francs; the operating expenses were 160 000 francs, or 30% of the receipts. The maximum grade was 2%; the smallest radius was 30 m. on the open road and 20 m. at the stations. This was, undoubtedly, the first time that such a record was made on a 0.60-m. gauge road with such primitive means, and we are used to such a showing on first-class standard-gauge roads only.‡

* Bau u. Betr. d. Schmalspurb., W. Hostmann, Wiesbaden, 1881.
Hostmann's Mittheil. über Lokalb., 1882. Ueb. d. Betriebsergebnisse, 1871–77.

† Dr. Röll's Encycl. d. ges. Eisenbw., I Band., 1890.

‡ "Das Eisenbahnw. auf der Weltausstellung in Paris," A. Birk, Z. d. V. deutscher Eisenbahnverw., No. 73, 1889.
"Die Pariser Ausstellungsbahn v. Décauville," A. Brunner, Z. d. V. Eisenbahnverw., No 6, 1890.
Le chemin de fer Décauville pendant l'Exposition de 1889, Corbeil, 1891.

5th. The Vicinal Railroad from Pithiviers to Toury, France, 31 267 km. long, of which 19.4 km. use the highways, has been built with a gauge of 0.6 m., maximum grades of 2.3% and 30 m. smallest radius, at an expense of 25 000 francs per kilometer. Six trains are run daily, with a maximum speed of 25 km. per hour.

6th. The Vicinal Railroad from Luc-sur-Mer to Dives, France, 29 km., built along the highways with a gauge of 0.6 m., has maximum grades of 3% and a smaller radius of 20 m. The cost was 35 000 francs per kilometer. Twenty-four trains are scheduled daily, with an hourly speed of 30 km. Each train seats 225 persons.

Considering the favorable results of the fore-mentioned French local roads, the General Council of the Departement de Calvados resolved, August, 1892, to adopt the 0.6-m. gauge also for the county system of secondary roads, comprising several hundred kilometers.

7th. The results of narrow-gauge roads in Hungary are contained in the following table:

Name of Railroad.	Gauge in meters.	Operated length in kilometers.	1890				
			Cost in florins per kilometer.	Gross receipts per kilometer in florins.	Total expenses in per cent. of gross receipts.	Net receipts in per cent. of cost of railroad.	Dividends of common stock, per cent.
Buda-Pesth-Szt. Lörinczer Railroad....	0.76	8.6	21 555	4 374	60.5	8.8	6.5
Gölnitz Valley Railroad.....	1.00	33.0	44 865	4 415	50.5	5.0	
Taracz Valley Railroad.....	0.75	32.8	19 750	472	58.5	1.0	
Marmaroser Railroad.....	0.75	40.3	22 446	2 425	35.5	9.9	4.5
Belisce-Kápolnaer Railroad.....	0 76	38.5	18 797	2 817	51.0	7.4	
Buda-Pesth Local Railroads.....	1.44	41.1	41 865	4 064	87.1	1.3	

At the end of the table the figures are given for the standard-gauge Buda-Pesth local roads. This line is operated under exactly the same conditions of traffic as the Buda-Pesth-Szt. Lörinczer Railroad, and furnishes a practical example showing how much more profitable, under the same conditions, a narrow-gauge road may be than one with standard gauge. The gross receipts are almost alike, but the operating expenses of the narrow-gauge road amount to 60.5%, and those of the standard-gauge road to 87.1%, of the gross receipts. The operation of the former is consequently more economical, though its length is 8.6

km. only, while the administration expenses of the latter road are distributed over 41.1 km.*

8th. The Agricultural Railroad on the Crown Estates Mezohegyes in Hungary, 0.76-m. gauge, opened in 1889, is 34 km. long, has maximum grades of 5%, smallest radii of 60 m. Cost, 7 500 florins per kilometer.†

9th. The Bosna and the Bosnian-Herzegovinian Government Railroads. Gauge, 0.76 m. The former was built as a supply road during the occupation campaign of 1878; it was very imperfect technically, and of small efficiency of transportation. The original cost averaged 20 900 florins per kilometer, but it has been gradually transformed and lengthened.

At present the system of the Bosna Railroad‡ consists of—

(*a*) The Bosnian Brod-Doboj-Zenica Railroad, 189.7 km., the cost of which reached 49 200 florins per kilometer. The smallest radius is generally 50 m., with exceptional curves of 35 to 40 m. radius. The invested capital of 7 410 311 florins brought 4.21% interest in 1891 against 5.73% in 1890.

(*b*) The Zenica-Serajewo division of the Bosnian-Herzegovinian Government Railroad, 78.6 km., cost per kilometer 48 157 florins, smallest radius 275 m., steepest grade, 8 per cent. The invested capital is 3 902 034 florins and paid 3.31% in 1891, against 4.39% in 1890. On this line, and on the above-mentioned Bosnian Brod-Zenica Railroad, 254 669 passengers and 172 935 tons of baggage, express and ordinary freight, were carried. Each passenger averaged 77.1 km., and each ton of freight 102.07 km.; 27.16% of the receipts belong to the passenger traffic. The operating expenses were 55.6% of the receipts.

(*c*) The Vogoscá-Cjevljanovic mining road, 20.5 km. Minimum radius, 40 m., steepest grade, 0.2 per cent. Average cost per kilometer, 5 765 florins.

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* "Die schmalspurigen Localb. in Ungarn." Z. d. V. d. Eisenbahnverw. No. 5, 73 u. 76, 1892.

† "Die landwirtschaftl. Industriebahn d. Mezöhegyeser Staatsgestütsgüter." Z. d. V. d. Eisenbahnverw. No. 90, 1892.

‡ "Die Bosnabahn." W. v. Nördling, Z. f. d. ges. L. u. Str. Bw. 1883. "Die bosnischen Bahnen." E. v. Gutenberg, Oest. Eisenbahnz. Nos. 14 u. 15, 1886. "Die K. u. K. Bosnabahn," 1879-1889, Serajewo, 1889. "Die Bosnabahn, speciell ihre bauliche Anlage." Z. f. d. ges. L. u. Str. Bw. 1890, Dr. Röll's Encycl., II Band, 1890. Der Bau u. Betrieb der K. u. K. Bosnabahn u. d. Entwickl. d. bosn. Eisenbahn. A. Obermayer. Oest. Eisenbahnz. Nos. 52 u. 53, 1882. Ueber Bau u. Betrieb d. bosn.-herzeg. Staatsbahnen, bes. d. Zahnradbahn zw. Serajewo u. Konjice, F. Pfeuffer. Z. d. oest. Ing. u. Arch. V. Nos. 22 u. 23, 1893. Bericht ü d. Studienr. in Bosnien, Mai, 1888. P. Kortz, Wochenschr. d. oest. Ing. u. Arch. V. Nos. 35 u. 38, 1888. Verordnungsbl. f. Eisenb. u. Schiffahrt No. 133, 19. Nov., 1892.

(*d*) The line Doboj-Sinnin-Han, 66.7 km., smallest radius 80 m., steepest grade 1%; cost per kilometer, 19 490 florins. The track is old steel rails, 14.2 kg. per meter, from the Tobuk-Zenica Railroad. In 1891, 74 841 passengers and 95 528 tons of baggage, express and ordinary freight were carried. Each traveler made on an average 29.8 km., and each ton of freight 44.55 km. The gross receipts are 135 584 florins, of which 22.65% are due to the passenger traffic. The operating expenses were 103.86% of the receipts against 65.29% in 1890.

(*e*) The division Metkovic-Mostar, 43.2 km., smallest radius 100 m., steepest grade, 3.33%; cost of construction per kilometer, 40 000 florins.

(*f*) The line Mostar-Ostrozac-Serajewo, 133.5 km. The Ivan Mountain is passed by the combined adhesion and Abt rack railroad system in a length of 15.14 km. On the mountain division the maximum grade is 6%, the smallest radius 125 m.; in the valley division the smallest radius is 80 m., and the maximum grade 1.5 per cent. The rails of the adhesion line are Vignol rails, weighing 17.9 kg., and those of the rack railroad weigh 21.8 kg. per meter. The division Mostar-Rama, 56 km., cost 50 000 florins per kilometer on an average, and the Rama-Serajewo division, 77.5 km., averaged 71 000 florins per kilometer.

This system, in its entirety, takes the place of a trunk line. There is an average of 3.3 trains per day with hourly speeds of 23 to 30 km. The number of trains in each direction can, however, be increased to 24. This alone refutes the supposed small efficiency of narrow-gauge roads for military purposes.

10th. The Saxon Narrow-Gauge Roads, 0.75-m. gauge, comprising 11 branches, having in 1889 a total length of 199.36 km., cost, on an average, 62 584 marks per kilometer. The annual receipts per kilometer were 4 673 marks, the expenses 3 059 marks, or 65.40% of the former. The capital paid 2.58% interest.

According to information obtained from the Royal Saxon State Railroads, these roads have proved highly suitable, and their gauge has rendered it feasible to confer the benefit of railroad connection, without a disproportionate expense, on villages remotely situated in side valleys and cut off from main lines by mountain chains.

11th. The Bari-Barletta Railroad in Italy, 0.75-m. gauge, carried 378 790 passengers and 94 100 tons of freight in 1886–87. During October the traffic amounted to 41 863 passengers and to 8 010 tons of freight, giving a yearly capacity of 500 000 passengers and of 96 000

tons of freight. The trains are composed of 10 to 12 passenger cars, and run at speeds up to 39 km. per hour.

12th. The Bolivian railroad from Antofagasta, on the shores of the Pacific, through the desert of Abacama to Ujuni and Oruro, has been in operation for two years up to Ujuni, in a length of 615 km.; it is being extended to Oruro, and the intention is to continue it later on the Bolivian high plateau to La Pas in the north, and to Suere in the east. The road has a gauge of 2½ ft. (0.76 m.), and is undoubtedly the most remarkable instance of a high plateau railroad. There are running over it at maximum grades of 3% even Pullman cars of 15-m. length; with two four-wheeled bogie trucks, transverse seats and a middle passage, and passenger cars 9 m. long on three transversely movable axles, with longitudinal seats and a center aisle.

13th. The railroad from Morvi, in Asia, 2½-ft. (0.76-m.) gauge, 94 miles (151.25 km.) long, has been in operation for five years. The annual average traffic amounts to 225 000 passengers and 22 200 tons of freight. There are regularly two daily trains in each direction, and the yearly operating expenses are 3 294 francs per kilometer or 64% of the income. The capital pays an interest of 4½ per cent.

14th. It may be finally mentioned that, in order not to burden the State finances too heavily and to make the income meet the expenses, it is intended to adopt the 0.6-m. gauge for the Peloponnesian railroads, on which a light traffic only can be expected. The cost is not to exceed the sum of 20 000 francs per kilometer under any condition.

II.—The alleged objection of the greater operating expenses of narrow-gauge roads, which are said to increase in proportion to the decrease of the gauge, is, according to the experience of practice, just as poorly founded as the objection that the smaller radii offer a greater resistance to the passing of vehicles. The latter has also been refuted by theoretical considerations and by actual experiments.

The cost of construction of German narrow-gauge railroads, with a total length of 1 051 km., gave an average of 52 124 marks in 1890–91, a comparatively very high sum. The annual working expenses averaged 3 210 marks per kilometer or 68.01% of the annual receipts of 4 721 marks per kilometer; the invested capital paid, therefore, 2.6%, which result would undoubtedly have been much more favorable if narrow gauge had been used.*

* Stat. d. in Deutschland im Betr. stehenden Eisenb. per 1890–91, Reicheisenbahnamt. Dr. Röll's Encycl., f. d. ges. Eisenbahnw., II Band, 1890.

The objection frequently raised that no cattle transports are possible on narrow-gauge secondary roads has also been removed by the fact that on the Bosna and on the Bosnian-Herzegovinian State Railroad, 0.76-m. gauge, four head of cattle or four horses are loaded into covered freight cars, 6.7 m. long, 1.66 m. wide and 2.15 m. high, and are transported without trouble. There are regular transports of cattle also on the Ocholt-Westerstede Railroad, 0.75-m. gauge, on the Broehl Valley Road, 0.785 m., and on the Salzkammergut Railroad, 0.760 m., and even on the Décauville Railroad, 0.6 m., the use of combination cars, 9.8 m. long, 1.7 m. wide, weight 4.7 tons, and of covered box cars, contents 20 cu. m., has proved a success for the carrying of cattle. The circumstance that approaches or inclined planes are dispensable in loading deserves special mention.

III.—The difference of gauge is an undeniable disadvantage in connecting with existing or projected standard-gauge roads, as an immediate passage of the rolling stock is impossible, and a changing of cars for passengers and a reloading of freight becomes necessary. But this drawback loses importance, if one decides to render possible a mutual exchange of cars by mechanical appliances. It must be mentioned, however, that their use necessitates the clearance profile of standard-gauge roads and so obliterates one of the essential advantages of narrow-gauge roads. If interchangeable car bodies, lifting derricks, etc, are used, the cost of rehandling becomes higher than with the ordinary system of reloading from car to car by hand. The International Railroad Congress in Paris in 1889 resolved that it is the simplest and cheapest to reload goods from car to car without mechanical apparatus.*

The above disadvantage does not at all enter into consideration where isolated roads are concerned, or those which are to form a new narrow-gauge system. The traffic of such roads is limited, there is no through traffic, and generally only the local traffic of the countries or provinces reached by the system has to be subserved. From an economic point of view, the secondary roads must be regarded as industrial enterprises, and their mode of operation must therefore bear a proper relation to the necessary requirements and special exigencies of each line, so as to economize as much as possible.

Moreover, the passengers ordinarily change cars at the junction

* Compte rendu sommaire du congrès international des chemins de fer, Paris, 1889.

stations of branch railroads of even the same gauge; and all cars not fully loaded, as well as express and parcel goods, are unloaded anyway, to avoid the payment of the high rent charged for the use of strange cars. The change of cars and the reloading of freight cannot therefore be regarded as unqualified disadvantages of the difference of gauge, as the reloading causes a maximum outlay of 18 to 30 centimes per ton, according to the nature of the freight, which is certainly less than the usual car-rent paid to the connecting road. Generally, the cost of reloading fully loaded cars has to be estimated at 200 to 300 francs per kilometer for a road 30 to 40 km. long, a sum far outweighed by the savings in construction and operation of narrow-gauge roads. It is evident that the necessity of reloading goods cannot form an essential obstacle to their development and earning capacity.

Some engineers regard as a technical disadvantage of narrow-gauge roads the supposed impossibility of using stable engines and cars on account of the narrow basis; engines and cars are further said to oscillate more, influencing the wheel pressures unfavorably, which would become objectionable very soon at a rapid and prosperous development of a railroad system; the small radii finally hinder an increase of speed.

The experiences of narrow-gauge roads prove, however, that the construction of rolling stock has already been so developed that those objections must be considered as not existing, which may be also inferred from the three tables, A, B, C, of the principal dimensions of locomotives, passenger and freight cars of different narrow-gauge roads, of the efficiency of locomotives, the dead weights of cars and their loading capacity. Investigations show that, even with the narrower gauges, the center of gravity lies very much lower, on account of the smaller wheel diameter, than with broader gauge cars; on the Décauville cars, 0.60-m. gauge, for example, it lies only 0.39 m. above the rails. The oscillations of narrow-gauge cars, running at the low speed of about 25 km. per hour, are very insignificant in any case. The train resistance in curves may be essentially reduced by a suitable selection of the wheel-base and the use of movable axles or of trucks and further by running short and light trains; it is, therefore, less injurious and dangerous than with standard gauge.

The question of the most suitable gauge for a certain volume of traffic, considering cost of construction and earning capacity, has long

occupied engineers and capitalists. The opinion is gaining more and more ground that standard-gauge roads are too large and expensive for a limited traffic, and that narrow-gauge roads have proved a quicker, better adapted and more satisfactory means of communication than standard-gauge secondary roads, which are shaped after the large railroads in their whole mode of construction, operation and administration.

Resolutions of the International Railroad Congress, 1885–1892.—The first International Railroad Congress adopted, in 1885, the following resolutions on the above issue :*

1st. "Secondary and vicinal railroads are to be considered as feeders exclusively, and shall be so constructed as not to deviate from their purpose.

2d. "Secondary railroads are to connect with the neighboring trunk lines ; they shall be received favorably by the administration of State and private railways, and shall find co-operation regarding :

"(*a*) The arrangement and distribution of expenses of joint depots;

"(*b*) The handling of incoming and outgoing freight;

"(*c*) The raising of capital for first construction under the most favorable conditions ;

"(*d*) The arrangement for transportation of construction material ;

"(*e*) The repairs of rolling stock.

3d. "Vicinal railroads shall be built on already existing highways, wherever circumstances permit.

"The Congress expresses the wish that the States, provinces and counties accord to the enterprises every relief compatible with wagon traffic concerning the utilization of the roads for track laying and depot construction as well as regards operation.

4th. "The Congress recommends the adoption of narrow gauge for secondary roads, as this will result in savings in construction and operation unattainable with standard gauge. It desires, further, that certain types of narrow gauge, for example, 0.75 or 1 m., be introduced universally, to the exclusion of intermediate gauges ; finally, that adjoining railroads of the same section of the country, which may enter into mutual traffic relations, use the same standards of gauge, draw and buffer appliances.

5th. "The Congress gives as its opinion, that the necessity of reloading cannot be considered as an obstacle to the development of narrow-gauge roads.

6th. "The Congress desires the greatest elasticity of the tariffs of

* Compte rendu général du congrès de chemin de fer. Bruxelles, 1886.

vicinal roads, according to the special conditions of each separate line, and wishes that the Governments fix their maximum tariffs considerably higher than those of large railroads, and afford to the incorporators more freedom in the use of the tariffs as well as the greatest possible easements in the specifications for construction and operation."

The Second International Congress, held at Milan in 1887, has ratified the above principles.*

At the International Railway Congress in St. Petersburg, August, 1892, the following question, XXXIV, was opened for discussion :†

A. "Which is the most favorable gauge for economic railways (*des chemins de fer économiques*) in the different cases (1.44, 1, 0.75 or 0.60 m.)?

"What are the circumstances and considerations giving preference to a certain gauge?

"Is there sufficient experience on this question?"

E. Radice, Technical Director of the Tessin Railway, acted as referee. To his printed report are annexed the reports of H. Fromm, Managing Director of the Dortmund tramcar lines, and of de Backer, General Director of the Economic Railway Company in Brussels, made, respectively, at the fifth and sixth general meetings of 1890 and 1891, together with the discussions held at these meetings. The latter will be considered separately.

The first part of the question, on the most favorable gauge for economic railways, created a lively debate. Several members declared themselves against the 0.6-m. gauge, because, in their opinion, it did not permit the equipment of the cars with the convenience desirable for travelers, and because trains could be run at low speed only. With 1-m. gauge, railroads use speeds of 50 to 60 km. per hour, inadmissible with a narrow gauge.

Others, however, were of the opinion that speed is not an excessively important factor in most cases, and that, if in some countries 1-m. gauge has been adopted for extended lines, such roads cease to be secondary roads; they will then be managed, operated and maintained like large railroads. Gauges less than 1 m. suffice fully for short lines. They claim that the gauge is not only a function of the speed, but much more of the first cost and of the maintenance; nature and importance of the traffic must further be considered. Experience

* Conclusions du congrès international des chemins de fer. Milan, 1887.

† Question XXXIV: Largeur de la voie des chemins de fer économiques. Bruxelles, 1892.

teaches, moreover, that even narrow-gauge roads are able to handle a very considerable and brisk traffic.

The following resolution was finally agreed upon :

" It is important for the evolution of secondary roads that the greatest liberty be left in the selection of the gauge. Each may be advantageous according to local conditions. It is a question to be solved from case to case, inasmuch as the special demands of a locality, the nature and the extent of the expected traffic have to be taken into account in order to justify a more or less expensive maintenance. But it is just as important that some defined standards be adhered to, which have already found a successful use in practice. The four types of 1.44, 1, 0.75 and 0.60 m. are the only recommendable ones." *

Resolutions of the International Permanent Tramcar Society, 1890–92. At the fifth general meeting of the International Permanent Tramcar Society, held in Amsterdam, the following resolutions were adopted on the question:

" What is your opinion and what personal experience do you possess concerning the most suitable gauge for steam tramcars, viz.:

" (*a*) Standard gauge ?

" (*b*) Medium gauge (about 1 m.) ?

" (*c*) Narrow gauge (about 0.75 m.) ?

I. " Narrow gauge is to be chosen for steam tramcar roads, except in some cases, especially where short lines connect with standard-gauge roads and have to handle a large and bulky traffic.

II. " Concerning a selection between the different narrow gauges, it appears that they do not offer advantages or disadvantages sufficient to entitle one or the other to preference. Experience shows that one and the other have been used almost simultaneously, and that both have given good results. A predilection seems, however, to grow for the 1-m. gauge."†

At the sixth general meeting, August, 1891, in Hamburg, no conclusion was arrived at, after a very heated discussion, on the question :

" What are, in your opinion, or according to your experience, after the adoption of narrow gauge for a railroad, the relative advantages or disadvantages of the three most commonly used narrow gauges : 1, 0.75, 0.6 m. ?"

It was resolved to put this question again on the programme of the next general meeting.

For the seventh general meeting, which was to be held in Buda-Pesth

* Z. f. Eisenb. u. Dampfschifffahrt, No. 38, 1892.

Conclusions et renseignements divers du congrès international des chemins de fer. Bruxelles, 1892.

† Prot. d. V. Gen. Vers. d. Intern. permanenten Strassenb. Ver. Brüssel, 1890.

in September, 1892, the writer was chosen referee on the above question, but the meeting did not take place for sanitary reasons. The author's comprehensive printed report on the subject comes to this final conclusion:

"The gauge is to be fixed separately for each case after mature deliberation, on the strength of accurate investigations on the present and expected demands of traffic and under full consideration of all local conditions and of the financial and other means at hand.

"Proper regard is further to be had for an economical construction and a simple and cheap system of operation, in order to insure a suitable percentage of interest for the expended capital." *

Principles for Construction and Equipment of Local Railroads Within the Sphere of the German Railway Union.—It must not be left unmentioned that the German Railway Union, in establishing principles for the construction and operation of local railroads, has recommended the 0.75-m. gauge for narrow-gauge roads according to the resolutions of Constanz, June, 1876; of Salzburg, July, 1886; and of the Berlin Engineers' meeting, May, 1890; it has consequently abandoned a uniform as well as the 0.6-m. gauge.

The code of rules for German railways of inferior importance, July 12th, 1878, fixes also the gauge for narrow-gauge roads at 1 or 0.75 m. Exceptions are admissible with authorization of the Government and with concurrence of the Railway Department.

Specifications for "Small Railroads" in Prussia, for which Gauges of 0.60, 0.75 *and* 1 *m. are Admissible.*—The above ordinances have, however, been modified by the new Prussian law, July 28th, 1892, on "Small and Private Connecting Railroads (Tertiary Railroads)," and the specifications of the Secretary of the Department of Public Works, November 18th, 1892, appended to the law, exact that, in the interest of the defence of the country, the ensuing regulations will be enforced on all railroads operated by engines:

I. TRACKS.

(*a*) Besides standard gauge, only 0.60, 0.75 and 1 m. gauges are to be permitted.

(*b*) Where ties are used, the minimum weight of rails must be 9.5 kg. per meter

(*c*) For the 0.6-m. gauge the smallest radius is to be 30 m.

(*d*) The inside clearance of rails at switches, crossings, crossovers, etc., must not be less than 0.035 m. (Regulations "*c*" and "*d*" do not hold good for tramcar roads.)

* Bericht d. Civ. Ings. E. A. Ziffer, f. d. VII Gen. Vers. d. Intern. perm. Strassenbahn Ver. Brüssel, 1892.

II. Rolling Stock.

(*a*) For roads with 0.6-m. gauge, locomotives and cars must be able to pass 30-m. curves without trouble.

(*b*) Wheels are to have one flange only.

(*c*) The rolling stock of railroads with 0.6-m. gauge must be equipped with central buffers, 0.30 to 0.34 m. above top of rails. The loading capacity of cars, given in kilograms, must be a multiple of 500.

III. Depots.

Where railroads with small gauge join such with larger gauge and a passage of cars is impossible, suitable arrangements for the transfer of goods are to be made. Where an existing line is being extended, the maintaining of gauge and weight of rail may be permitted, even if neither should conform to Regulations I, *a* and *b*.*

Introduction of the 0.6-m. Gauge on All New "Small Railroads" of Mecklenburgh.—The Diet of Mecklenburgh has ordered the introduction of a uniform gauge of 0.6 m. on all new "small railroads." At the discussions, the fact was referred to that this is the standard gauge for the Prussian military administration, especially on fortress railroads; it was further stated, that influential French circles had emphasized the necessity of first considering the defence of the country in building "small railroads," and that, as France possesses a great number of 0.6-m. gauge roads, the result of the French deliberations has been to establish the principle to use 0.6 m. only, and to take standard gauge at once if a larger gauge should become necessary.

The Friedland "Moorcultur" Railroad and the "small" road from Friedland to Vorpommern have given eminent satisfaction, and their operation is entirely safe for passenger as well as for freight traffic. The danger of a tilting of the cars, which are built on the truck system, does not exist. The 0.6-m. gauge is further unobjectionable as regards speed. On the Friedland road this is limited to 14 km. per hour; but a similar "small" road in Sweden, near Kosta, which has been in operation for seven to eight years, runs trains at an hourly speed of 35 km. with authorization of the Government.†

Final Conclusions.—In summarizing the investigations, experiences and conclusions on railway gauge, we find that standard gauge has been adopted in the European States for trunk lines, with the exception of Russia, Spain, Portugal and Ireland, which use a broader

* Verordnungsbl. d. k. k. Handelsmins. f. Eisenb. u. Schifffahrt No. 144. Dez., 1892.
† Z. d. Vereins deutscher Eisenbahnverw., No. 98, Dez., 1892.

gauge in addition to standard, and Greece, which uses a narrower gauge; in the other countries, broad, standard and narrow gauge exist, and either the one or the other is in exclusive or prevailing use, or, generally, all three systems find use. The fact deserves attention, that in the younger, principally the transoceanic countries, narrow gauge has, from economic reasons, been also taken for main lines; in these cases 1-m. gauge has preferably been chosen.

For secondary (local and vicinal) railroads, as well as for all roads of inferior importance which subserve limited interests and accommodate principally local traffic, standard and a great variety of narrow gauges have been adopted. The latter have been chosen in just appreciation of their economic advantages in construction and operation, and in spite of prejudices propagated from different quarters, frequently even by engineers, and of a systematically conducted opposition against the narrow gauge. Their great advantages, especially from the standpoint of economy and earning capacity, are, however, indisputable, though it must be admitted that, due to a few minor disadvantages of narrow gauge, standard gauge may become desirable for secondary roads; for instance, where existing standard gauge roads are to be connected or extended, where the country is perfectly level and right of way unexpensive, or where, by utilizing broad and level highways, any acquirement of real estate is avoidable.

Generally, the narrow gauge may be regarded as the most rational solution of the question of a simple and cheap construction and operation of secondary roads, even for a not inconsiderable traffic.

Likewise, narrow gauge is also to be recommended for main lines in countries with a presumably moderate traffic, and where the financial status necessitates the greatest possible economy, so that the invested capital may pay a good interest as quickly as possible.

It remains now only to select a suitable gauge for narrow-gauge roads. The writer thinks that only the three gauges 1, 0.75 and 0.60 m., which have found the most extended use so far, should be taken into consideration; but he also believes it very dangerous to recommend the exclusive use of one or two gauges, or to prohibit the introduction of one of them. The selection of the gauges is, therefore, after careful commercial and technical investigations, to be made dependent on the demands of the present and expected traffic, on its nature and on the local exigencies, and finally on the financial and other means

at hand ; the presumable earning capacity of the investment has to be fully considered. The gauge must be determined in each separate case after a mature deliberation of all existing circumstances.

It must further be acknowledged that narrow-gauge roads, even with 0.6-m. gauge, can accommodate a large traffic, and that they always require a smaller outlay. It is finally apparent that, if secondary railroads are to continue in a successful development, they must enjoy full liberty regarding construction, operation and administration, and must be built, organized and managed on standards different from those of main lines.

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RAILWAY SIGNALING.

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Translated from the German by GEORGE F. SWAIN, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Although the question in railroad signaling between the system of time intervals and that of space intervals has been universally decided in favor of the latter, yet there are still some very important matters regarding signaling which, on account of fundamental differences, may be worthy of a detailed discussion. The first point relates to the use of colors for night signals.

According to general usage, red means danger, "stop"; green means caution, "run slowly," and white means "all clear." The disadvantages of white light, however, have induced many companies to abandon its use at fixed signals, replacing it with green as a safety signal. This system has the advantage that in case of accident or breakage to a colored screen or glass, white light appears, which is considered a danger signal; whereas, if white is a safety signal, the breakage of a red glass or lantern may result in a false signal. This can occur, for example, in the case of the distant signals of the German

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

signal system, and in those of the American block systems of Hall, and the Union Switch and Signal Company.

This diversity of practice is therefore accompanied also by some further differences, for while the English distant signal acts as an imperative signal to stop, the distant signals just named simply indicate the position of the following home signal.

There is further a substantial difference between the German practice of operating signals on one mast and the practice in other countries. In the latter there are just as many semaphores or lanterns above one another as there are branches from one approaching track, all of these in their normal danger position being visible and showing red light at night, while in the German system the upper arm only is visible and shows red light at night. Where it appears necessary to control the movement of trains to a branch by signals on the same mast with other signals, the mast is provided with two or three semaphores and the same number of lanterns, one above another. The lower semaphores and lanterns are used only to give safety signals to a train diverging from the main line; in case of a signal to stop, or in case of a signal to proceed on the main line, the lower arms are vertical and the lanterns are invisible. By this arrangement the locomotive engineer never passes a red signal; but it has the disadvantage that an all clear signal gives no information as to which track is clear. The number of semaphores is, moreover, limited to three; if a greater number is required, they must be placed upon more than one mast. This limitation does not exist outside of Germany; one mast, especially at large terminal stations, often carries four or more semaphores, which give a very clear idea, not only of the number of diverging tracks, but also in regard to their directions.

Finally, a marked difference exists in the operation of signals at stations.

In England and America the different portions of a station and yard are independent sections, protected in all directions by signals, and to which the intermediate station tracks bear the same relation that the tracks of the main line bear to the adjacent block stations.

In Germany, on the contrary, the entire station is considered as a whole. The entire operation of signals and movement of trains at the station is made dependent upon one officer, who also, as a rule, has charge of the dispatching of trains.

In order to secure the dependence of the operators in the towers upon the orders of the managing officers of the station, there are special block appliances, which are operated from a suitable office in the station building.

Part I.—In General.

1. Introduction.
2. Signal systems.
   System of time interval; system of station or space interval.
3. Signals in themselves.
   Discs; semaphores; colors for signals; reflecting signals.
4. Apparatus for operating signals.
   Rods; wires; wheels; Austrian distant signals; Hipp's signal; Dumont and Postel-Vinay; Hall's signal; Currie and Timmins; Union Switch and Signal Company; American Pneumatic Company; Bianchi and Servettaz.
5. Fog signals.
   Torpedoes; bells; alarms; fog horn; apparatus acting on the engine.
6. Control or tell-tale apparatus.
   Duplicate signals; ringing apparatus; signal repeaters; galvanoscope; control of illumination of signals.

In General.

Introduction.—When it is remembered what an important and indispensable factor signaling is in the operation of railroads to-day, that engineers are constantly striving to perfect it in every direction, that every force of nature is utilized and every new discovery at once applied, it can scarcely be realized that the first railroads in England were operated without signals. Yet such was the case. The first railroads, however, were on about the same plane as the horse railroads to-day. Moreover, they were operated only during the day and generally with but one engine, and the speed was not over 10 miles per hour (16–17 km.)

Further, the Manchester and Liverpool Railway, which was opened September 15th, 1830, had engines without whistles; they, therefore, lacked even the signal of which M. M. von Weber in his book, "Railroad Telegraphy and Signaling" (which although old is still readable), says that it seems to us now the very voice of the railroad system,

whose tones show its whole character, and to which the soft tones of the post horn compare as the poetry of travel in early times compares with the restless travel of to-day.

An accident led George Stephenson to conclude that his engine could make 22 miles per hour, but that in order to exceed this speed a clear track must be provided. This led Stephenson to introduce a special signal system, in which he made use principally of colored discs on tall poles, which were held or turned by special watchmen. When, in 1836, it was found practicable to run at night, colored lanterns were fastened to the poles, which were used in the same way as the colored discs in the daytime. The trackmen were provided with red or green cloth flags, with which they could signal a train to stop or to run slowly where they considered it necessary.

Railroad signaling, not only in England, but in other countries, was developed from this idea of Stephenson's. It would carry us too far, and exceed the limits of this paper, to follow all the changes in the development of signaling up to the present day. The writer will, therefore, confine himself in the following pages to giving an idea of the present condition of signalling in the various civilized countries.

Systems in Signaling.—In general, signal systems may be divided into two almost diametrically opposed classes.

The first and original system is that with a time interval. It prevents the too close approach of trains running in the same direction by providing that they shall follow each other only after stated intervals of time, and that the following train shall be signaled to proceed slowly or to stop, unless the prescribed time interval has elapsed since the passage of the previous train. The time interval varies with the speed of the trains. This system was soon proved unsafe by the occurrence of several bad accidents arising from the fact that the signal men were not always reliable, or that they could not always give the signal at the right time. The introduction of electricity, moreover, made it possible to abandon the system of time interval, and to substitute that of a space interval between trains, independent of their speed.

The fundamental principles of these systems, both of which are still in use, may be thus summarized:

1. *Time Interval System.*—The track is clear if no signals are shown. A visible signal does not mean "stop," but allows a train to proceed with caution.

The block system, so far as introduced, is not an absolute block, since it allows more than one train or engine to be in the same section and on the same track at the same time.

2. *Space Interval System.*—The track is normally blocked; the visible danger signal is changed to a visible safety signal when the track is clear.

The block system is an absolute one, *i. e.*, only one train or engine is allowed on the same section and on the same track at the same time.

Signals in Themselves.—Signals are either audible or visible signals. The latter differ as to color and as to form.

The investigations of the brothers Chappe, the inventors of optical telegraphy, are of the greatest importance for the science of railroad signaling. Unfortunately, their results do not appear to be sufficiently known to railroad men, since they have been frequently disregarded. One of the most important results is that the color of any body may disappear under certain conditions of illumination, so that only the form and not the color can serve for a reliable signal.

For day signals, color was therefore very soon abandoned as giving any particular meaning, and it is now used principally as a means simply of increasing the visibility. A complete disc transverse to the track and turned towards an approaching train generally means "stop," while a disc parallel to the track, presenting its edge to an approaching train, means "all clear." Since the edge of a disc is as good as invisible, a disc rotating about a vertical or horizontal axis appears to be the best signal for the time interval system. The signal to proceed with caution cannot be given with the disc.

The experiments of the brothers Chappe showed further that a narrow and long surface could be seen farther than the same area in the form of a circle or a square; and that in average conditions of the atmosphere and on cloudy days, a body 6 ft. long and 1 ft. wide, projected against the horizon, could be seen by the naked eye at a distance of 6½ miles (10 km.). The form of signal chosen by the brothers Chappe, as a result of their experiments, and which they called a "semaphore," consisted of an arm hinged at one end which was attached to a mast. This has proved a most excellent signal for railroads. It is not only more plainly visible than a disc, but in addition to the vertical position, meaning "safety," and the horizontal position, meaning "danger," an intermediate position at 45° may mean "caution."

While these signals were soon adopted by all roads as day signals, it was necessary to come to some agreement regarding the meaning of colors for night signals. This was the more important because in England frequently one railway was used by trains and engines of other railways, and it was therefore important that the same color should always mean the same thing.

In February, 1841, there was held at Birmingham a congress of English railway men, at which uniform rules for signaling were adopted, especially with regard to the meaning of colors. It was decided that red should mean "danger," green "caution," and white "safety."

In view of the fact that at the instant of danger colored objects were not always at hand, any object or light swung violently was to mean "stop."

These rules were so simple and practical that they were accepted throughout the world, and are still in general use, although with the added idea that red means "stop" and green "proceed slowly." The Birmingham convention fixed therefore the basis of our modern signal code.

The choice of colors, however, was limited. The experiments of Chappe showed that if the visibility of a white light is taken as one, that of a red light of equal intensity is one-third, of a green light one-fifth and of a blue light one-seventh.

In choosing three colors for signals, therefore, white, red and green are the best, on account of their greater visibility. Against blue may also be objected that under artificial illumination it may appear green. Since the danger signal is the most important of all, it might appear advisable to choose for it the color possessing the greatest visibility; but white lights are so frequent, especially near cities, that it can scarcely be considered as a signal. For the danger signal, therefore, the color was chosen which was next to white in visibility, namely, red, while green was taken for "caution," leaving white for "safety."

The properties of white light, however, are likely to exercise a disturbing influence in many respects. In the first place, on account of its greater visibility, it is able to partially or wholly obscure neighboring colored lights, a circumstance which may have serious results in railroad operation. Moreover, the safety signal must frequently be changed into the danger or cautionary signal, which is generally done by moving a red or green glass in front of the white light. Movable

glass blades or screens, especially if exposed to the weather, are easily broken, and should this occur, it might happen that when a signal was set at danger it might still show white light, an approaching train would get a false signal and an accident might result. Even though it should be very seldom that signal screens were broken without being noticed by the operator or the trackmen, it nevertheless seems undesirable to arrange signals in such a way that a red or green might by accident be changed to white.

When, therefore, in England, the block system was introduced, in which when a section is occupied the entrance of another train is forbidden, and when free, another train is allowed to enter with undiminished speed, the cautionary signal was discarded. This opportunity was at once seized to discard white as a color signal; and the danger signal is now red, while the safety signal is generally green. Under this system, if white light is shown at any signal, the engineer is to consider this as a danger signal and proceed accordingly, thus obviating all danger of misunderstanding. Since, therefore, only two ideas were to be expressed by signals, in the case of semaphores the vertical position (which is really no signal at all) could be also discarded, and danger expressed by the horizontal position, while safety was expressed by the inclined position. Thus the day as well as the night signals gave definite expression to the two ideas, and the semaphore became the most suitable signal for the space interval system.

Where white light has been abandoned as a signal, some slight confusion of ideas has, it is true, resulted from the fact that, while green is the safety signal at fixed signals, it has remained the cautionary signal in the case of hand signals or temporary signals where track repairs render them necessary. This disadvantage, however, considering the ease of distinguishing the two cases, may be considered to be only theoretical and of no importance in comparison with the practical advantages in point of safety, resulting from abandoning white light as a signal at permanent signals.

If white light is used, it is advisable to let it shine through an opening of $\frac{5}{8}$ to $\frac{7}{8}$ in. diameter in the center of a dark glass, *i. e.*, to make it a so called "star-light."

The experiment has repeatedly been made to provide a signal which should have the same appearance at night as in the daytime. The simple illumination of the day signal, even with the electric light, has

proved insufficient, and specially formed signals capable of powerfully reflecting the light have been found necessary. For example, the Eastern Railroad of France had at its junction points signals whose arms were illuminated at night by white light from lanterns placed in front of them; the flat surface of the arm was covered with small mirrors arranged in such a way that they each reflected the light from the lantern parallel to the track, so that the signal presented the same appearance by night as by day to the engineer of an approaching train. Also some of the signals prescribed by the new French signal rules have arms covered with small reflecting strips illuminated at night with white light.

In the *Railroad Gazette* for 1888, page 201, a signal is described, constructed by the Union Switch and Signal Company after designs of Spicer and Schreuder, consisting of a concave arm whose back surface was a slightly concave mirror with a lamp situated in the axis and which reflected the light through a glass plate forming the front of the arm. In the same volume of the *Railroad Gazette*, page 684, Koyl's semaphore is described, which consists of a portion of a paraboloid of revolution whose vertex is in the mast, while the flame of the lantern is in the focus. This is said to be clearly visible, at night and under ordinary atmospheric conditions, at a distance of half a mile, in form, position and color. It is used on the Lehigh Valley Railroad, and is said to work well.

Apparatus for Operating Signals.—The direct setting of a signal by hand is seldom possible, hence, to transmit the movement, either rigid rods or wires are used, or else electricity, compressed air or hydraulic pressure.

The fundamental principal to be observed is that a safety signal shall at once automatically go to danger in case of any failure or accident to the mechanism for transmission. It follows that every signal must be placed by positive action in the safety position, and must go by its own weight or by an attached counterweight to the danger position.

Rigid rods, 1¼ to 1½ ins. in diameter, supported by rollers every 6 to 10 ft., are simple and not more expensive than wires up to distances of 550 ft.

The effect of temperature upon the length of the rods is very simply provided for by inserting equal armed levers, dividing the en-

tire length into two or more parts, so that the length of rod exposed to tension equals that exposed to compression. In the case of short rods or incomplete compensation, the throwing mechanism is given a greater travel than is necessary to throw the switch or signal, so that a part of the travel before and after the apparatus is thrown is without effect on the position of the switch or signal.

In most frequent use are wires or wire ropes, from $\frac{1}{8}$ to $\frac{1}{4}$ in. in diameter, either single or double.

A single wire is quite sufficient for setting a signal at safety, but it has the disadvantage that a person desiring to tamper with the signal may pull the wire or raise the counterweight, and thus give a false safety signal. In fact, several accidents in Germany have been traced to this cause, so that it has become the general practice to use double wires, with which tampering with the signals is impossible.

Long wires are open to the objection that they may become more or less inoperative, or even give a wrong or dangerous signal on account of changes of length due to temperature. A wire half a mile long changes its length about 8 ins. if the temperature changes 36° Fahr., and this is almost equal to the travel necessary to reverse a signal. With long wires compensation apparatus is therefore necessary to obviate the effect of change of temperature. Simple screw connections (turn buckles) inserted in the line of wire are not sufficient, since they would require continual attention and adjustment. It has been necessary, therefore, to resort to automatic devices. On the French roads, where single wires are principally used, a very simple and practical method is employed. It consists essentially in letting the end of the wire farthest from the signal pass over a roller, keeping it in uniform tension by a weight; to throw the signal, the movement of the lever clamps and carries along the wire, which is released when the lever is reversed.

Double wires, as generally used in Germany, need, up to a certain limit, no means of compensation. The wire is given an initial average stress, after which the stress changes with the temperature, the length remaining the same. This is perfectly practicable up to a length of a quarter of a mile. For greater lengths a compensating device is employed, in which the essential idea is to have both wires strained equally by equal weights hung upon them at the middle or at one end of the line, so arranged that a change in the stress of either wire by

pulling or releasing it automatically clamps the weights and allows the signal to be operated.

To support and guide the wires, guide wheels are placed at distances of 50 to 65 ft. apart, fastened to small posts. On straight lines the wheels are vertical; on curves they are more or less inclined, in order that the wire may not leave the groove. Recently the wheels have been fastened to the posts, hinged in such a way as to be free to automatically assume the proper inclination on curves.

Electrical Throwing Apparatus.—On the roads of Austria-Hungary it is a fundamental principle to use electricity only to release or to catch the throwing mechanism, the moving of the signal being effected by this mechanism, which is actuated by a weight.

Almost all the signals used on the roads of Austria-Hungary are constructed in accordance with this principle, from the first ones sent to the Paris Exhibition of 1867, by Leopolden, to those exhibited by Langié at the Paris Exhibition of 1878, and those shown at Vienna in 1883 by Pollitzer and by Sandorf. The release is effected by batteries or by induction currents.

On the Swiss roads, a distant disc signal, made by Hipp, is frequently used, which, however, requires a separate conductor for each of the two positions of the signal. The development of electrically operated distant signals in Switzerland and in Austria has, however, been arrested in the last few years by the fact that in these countries the safety appliances used for the protection of large stations have steadily increased, and for these it is prescribed that wires shall be used for setting the distant signals.

For operating the disc signals of the Eastern Railroad of France, Dumont and Postel-Vinay have used an apparatus in which the releasing and the arresting of the mechanism is done electrically. The mechanism itself is similar to Siemens and Halske's single wheel or spindle alarm apparatus. The operation of the signal is effected by breaking or closing the current through an electro-magnet in such a manner that the signal is clear as long as the current is closed, but goes at once to danger when it is broken.

In Hall's signal the electric current serving the signal brings into action, not a mechanism, but the electro-magnet of a powerful local battery. The apparatus works with a closed circuit. The signal is given by a disc of red silk within a water-tight casing on a signal

pole. The case has a circular opening on each side facing an approaching or receding train. The disc is held in the all clear position by an electro-magnet, through which a permanent current passes. If this current is broken the red disc is released and becomes visible at the opening. In the daytime the disc is illuminated by the daylight from behind it; at night by a lantern placed behind it. Recently, according to statements of Messrs. F. Büte and von Borries, this signal is said to have been made in the form of a blade, and the colorless glass behind it replaced by a pane of ground glass. The signal then has the same appearance by day and by night. When used as a distant signal, green silk is used instead of red.

Hall's signal is extensively used on American roads, and is highly spoken of. In quite a number of electrically operated signals used in America, open circuits as well as alternating induction currents are used. They have the peculiarity that the signal arm rotates about an axis close to its center of gravity.

Noticeable also is the semaphore signal of Currie & Timmins, of London (shown at the Paris Exhibition of 1889), in which, also, the signal is set by electricity. Specially constructed tubular electro-magnets are used, which attract the armature up to a distance of 3 ins. with approximately uniform force. At night the signals are given by incandescent lamps, and for this purpose the semaphore has a contact which, according to the position of the arm, sends a current to the red or the green lamp. The bulbs are colored.

The Union Switch and Signal Company, in Pittsburg, has developed a system, devised by Westinghouse, in which compressed air is used to operate the signals. The semaphore is normally horizontal, and is held in this position by a counterweight. At the foot of the mast is a reservoir of compressed air, and on the mast is a cylinder whose piston is connected with the signal arm. When compressed air is let into the cylinder, its piston is forced down, and carries the signal to the safety position. This operation is effected by an electro-magnet, whose armature opens a valve to which it is connected. When the current is broken, a spring closes the valve and allows the compressed air to leave the cylinder, and the counterweight then carries the signal to the danger position. Any failure of the current brings the signal to danger.

The American Pneumatic Company, of Boston, has introduced an

automatic system for block and other signals, in which a current of air serves to transmit the motion. The signal is moved by a train of mechanism which is operated by the movement of a track lever. The release of the mechanism is effected by a bellows, which is set in operation by the pressure of the first wheel of the engine. The air contained in the bellows is forced through a lead pipe $\frac{3}{8}$ in. in diameter, with a velocity of 600 ft. per second, to a reservoir at the foot of the signal mast, which is closed by a diaphragm. With this diaphragm is connected the release of the mechanism. Each signal is generally connected with two pair of bellows, of which one brings the signal to safety, the other to danger.

By the arrangement just described, not alone signals, but other signal apparatus, can be operated, such as screens, alarms, and even crossing gates. On the pipe from one bellows 6 to 8 connections can be made, provided they are all to be operated in a certain direction at the same moment.

Recently the Italians Bianchi and Servettaz have made successful attempts to use water, though inelastic, to transmit the motion for setting switches and signals. To prevent freezing it is mixed with glycerine. The water is stored in an accumulator under a pressure of 50 to 60 atmospheres. The movement of a switch is effected by means of two simple cylinders having the same piston. For operating a signal one cylinder is sufficient, the hydraulic pressure giving the safety signal, while the signal is carried to danger by a weight when the pressure is removed or in case a pipe breaks.

Fog Signals—The worst enemy of safe railroad operation is fog, which not only prevents the engineer from seeing the track ahead, but also obscures danger signals. Various means have been tried to remedy this evil.

Thus far the most successful are torpedoes, of which for safety two are placed upon the rail at a suitable distance in front of a danger signal, and which must be removed when the signal goes to safety. Torpedoes are used to signify "stop at once."

The repeated putting on and taking off of torpedoes is rather troublesome if it is done by special watchmen. The danger of mistake and the danger of walking on the track in a fog have led several roads to have recourse to special devices by which the torpedoes are placed upon and removed from the rails by mechanical apparatus interlocked

with the signals. But even these devices are open to the objection that they require personal attention in order to replace at once every exploded torpedo with a fresh one. The attempt has therefore been made to do even this automatically, within certain limits, and also to remove the uncertainty attending the blow struck by the rolling wheels. To accomplish the last result a special striking apparatus is introduced between wheel and torpedo, as in the "revolver torpedo" of Scholkmann and the torpedo signal used on the New York elevated roads at turnouts and crossings. In the first named, 12 pair of torpedoes are placed in a drum, thus serving for quite a series of signals; in the latter the torpedoes are replaced automatically from a supply chamber.

Another kind of fog signal consists in connecting the distant signal with a bell having one or two hammers, which rings when the signal is at danger. The motion of the hammers is derived from a track lever which is alternately depressed by each wheel of the train and raised by a spring. When the signal is at safety, the lever is depressed so as not to be touched by the wheels.

On the Government roads of Alsace-Lorraine the signal disc of a distant signal is replaced by a shallow bell against which the hammers strike when the signal is at danger. The bell is horizontal when the signal is at safety.

On other roads alarms are in use like those of alarm clocks. They consist essentially of a clockwork actuated by a weight, which is released by means of a lever close to the rail. The bell is struck rapidly by a hammer, and rings until after one revolution of one of the gear wheels it is automatically stopped.

The firm of Max Jüdel & Company, in Brunswick, has recently proposed to improve distant signals by the addition of a fog horn, which is to be blown by a pair of bellows operated by a track lever close to the rail. It is a remarkable fact that the fog horn is more effective when the sound follows the train than when the horn is blown in front of the train.

Other devices are those intended to operate directly upon the locomotive whistle or upon the train brakes. All these devices, however, require, in addition to an appliance between the rails which is raised or lowered according as the visible signal is at danger or at safety, a special mechanism in the locomotive, which, when the distant

signal is at danger, comes in contact with the raised bars between the rails, and blows the whistle or sets the brakes. The necessity of applying such apparatus to every locomotive which runs over the road limits the general application of this kind of device.

Tell-Tale Apparatus.—It is of the greatest importance that the man operating a signal shall be assured that the signal has actually taken the desired position. This is easily attained in the daytime when the signals are near by. In order to inform him with certainty at night, the lamp is allowed to shine backwards as well as forwards, with different colors, according to the position of the signal, excluding, however, the signal colors red and green.

When the signal is farther away, or when it is invisible to the operator on account of intervening obstacles, special devices are necessary which, partly mechanically and partly electrically, inform the operator or station agent of the position of the distant signal. The mechanical devices consist of duplicate signals, which follow the motions of the principal signals, but are set up in view of the operator. In course of time these have been discarded as too unwieldy, and at present electrical apparatus is principally employed.

The simplest, yet absolutely reliable, device is the bell generally used on the French roads, called "Trembleuse." These bells stop automatically; they ring only when an electric current passes through the tell-tale circuit. When the distant signal is normally at safety, the current is broken, and is only closed when the signal goes to danger. As long as the bell rings the operator is sure that the signal is at danger.

Similar tell-tale bells are used on the Austrian roads.

For signals which stand normally at danger, these bells are not suitable, since they cannot be rung continuously; while if the circuits are changed so that they only ring when the signal is at safety their silence would afford no security that the signal really was at danger. Moreover, if they ring almost without interruption they are often unendurable. F. Gattinger has therefore constructed an automatic current breaker which by means of a swinging disc or a pendulum only closes the current, say, every second.

In England visible tell-tales are universally used which not only indicate the position of the signals, but also show the operator an actual view of the signal itself, and are therefore called "signal repeaters."

An excellent tell-tale is the galvanoscope, if properly arranged ; in this, however, as in all electrical tell-tales, one position of the signal should not be indicated by an interruption of the current, since the same effect might be produced by a break in the circuit. On the other hand, there ought to be a current in the circuit, both when the signal is at danger and when it is at safety, while a third position shows a break in the current or some accident to the circuit.

It is also of the greatest importance that at night the signal lanterns be really lighted. In most cases this is assured by simply letting the lanterns throw their light backwards as well as forwards. The position of the signal, however, may render this simple means impossible. In such cases, electrical control apparatus is made use of. This consists in a contact apparatus in which the making or breaking of the current is effected by the change of length of metal strips, due to the burning or extinguishing of the lamp. The contact apparatus must be very delicate in order to indicate after a few seconds the extinction of the lamp. In the operator's room there is an indicator consisting of a galvanoscope which, when the current is broken, shows behind the little window of the case a colored disc with a notice such as "light out." Sometimes, also, alarms are inserted in the circuit, which ring when the lamp goes out.

Part II.—Application of Fixed Signals.

1. English signal system.
   Distant signal; home signal; station signals.
2. Belgian signal system.
   Distant signal.
3. French signal system.
   Circular discs; protection signal; square signal discs; junction signals; facing switch signals.
4. German signal system.
   Continuous line signals; distant signals; home signals; mast signals.
5. Position of signals.
   Distant signals; local or home signals; station signals.

1. *English Signal System.*—In foggy England, where in order to avoid highway grade crossings the railways lie frequently in deep cuts, and have many curves, it was soon found that, in order to surely

prevent accident at any point of danger, it was necessary to place the corresponding signal at a considerable distance from this point. Thus arose the "distant signal," which is a characteristic of the English signal system. By its means head and rear collisions were guarded against, long curved cuts and tunnels that could not be seen through were protected, and it was also possible to communicate definite information or instructions to points a long distance away, or when a station or other portion of the track was blocked, to prevent a too close approach of trains to each other.

In the congress at Birmingham, already mentioned, it was agreed that signals should normally stand at danger.

If the distant signal is at danger it presents to an approaching train by day the full round disc or the horizontal blade, and at night red light. If it is at safety, the disc shows only its edge, or the semaphore is inclined at 45 to 60°, or at night green light is shown. If a locomotive runner sees his distant signal at danger, he must at once shut off steam and apply the brakes, so as to be able to stop at the distant signal. If he then sees that the track is clear, he is to proceed slowly, covered by the distant signal, always keeping his train under such control that he is able to stop quickly if any obstacle appears.

If a train has run by the distant signal, and is near the point of danger (the end of a section in the case of the block system, or the switch in the case of a junction or the entrance to a station, or a grade crossing, etc.), it is then necessary to give the engineer definite orders as to his future movements. For this purpose a "home" signal mast is erected at a suitable point near the point of danger, carrying a blade distinguished from that of the distant signal by having a square end while the distant signal blade has a notched end.

If several tracks diverge from one main track, as many blades are generally placed above one another on the home signal mast as there are tracks for an approaching train. The rule is that the blades from top to bottom correspond to the tracks from left to right.

At night, the home signal shows the same color as the distant signal. No engineer is allowed to run by a home signal at danger.

Station signals are generally placed behind the home signals at block, junction, or other stations, and regulate the departure of trains. They resemble the home signals completely in form and meaning.

2. *Belgian Signal System.*—On the Belgian roads the signal system

has been developed quite closely after the pattern of the English. The home signals are precisely the same, in form and meaning; the distant signals, however, differ in form considerably from the English. They are in the form of discs, to distinguish them better from the home signals; and in order that they may conform to the principle of giving definite signals for safety and danger, they show when at danger an elongated rectangular blade, or at night red light, and when at safety they present a square disc, or green light.

3. *French Signal System.*—The distant signal was adopted in France in its original form of a rotating disc, and this form has been preserved to the present day. Indeed, France is the country in which the fewest experiments have been made in signaling. The French roads are even to-day operated for the most part by the system of time interval, and this system has become such an integral part of the French railroad system that notwithstanding its defects, comparatively good results are attained with it. In consequence, safety is generally indicated by the absence of signals.

In addition to the distant signal, the original English color code was adopted, so that in France red stands for danger, green for caution, and white for safety.

Semaphores as distant signals have been used only on the Lyons road.

When the French distant signal is at danger, it shows a circular disc or a red light. In the safety position the disc is parallel to the track, and white light is shown at night. When an engineer sees a disc or a red light, he must at once reduce speed and proceed only at such a speed that he is able to stop within the length of track in sight, should he see any obstacle, or another danger signal. In any case the train must be brought to a stop either before the first switch or the first crossing of railway or highway, or before the point for which the disc serves as the signal, and it can only proceed under further signals or verbal instructions from the conductor or the station master.

To each circular disc corresponds a protection signal (*disque de protection*), illuminated at night, which shows the point beyond which the disc affords protection, except in bad weather. If, therefore, a train which has run by a disc signal stops before its rear has reached the protection signal, it is not to be considered as sufficiently protected in the rear.

Besides these, square (home) signal discs are in use on the French roads, which are located close to the points to be protected. When these show the full disc, or at night a double red light, they command an immediate stop.

The normal position of the distant signal is at safety, but it stands at danger, of course, as long as the home signals at danger.

Junction points of French roads are protected by distant signals, which present the same appearance by day as by night, namely, in white letters on a green field the word "Bifur" (caution). At such signals the engineer must prepare to stop, should it be necessary, at the square home signal for which the junction signal is the preparatory or distant signal.

Finally, signals are erected in front of every facing switch (*signal de direction*). These signals consist of a mast upon which are placed as many arms, one above the other, as there are diverging tracks. The arms, from top to bottom in order, refer to the tracks in order from left to right. The arms are hinged at their centers of gravity, and can assume only two positions, viz., the horizontal, which is a stop signal for the track to which it refers, and the inclined position, which denotes that the switch is set for the track in question. At night, the horizontal arms show violet light, the arms inclined obliquely downward show white light, or green light if the switch is to be taken at a reduced speed.

On approaching a junction or a facing switch provided with signals, the engineer must indicate the track he desires to take by a corresponding number of long blasts of the whistle, without regard to the position of the signal.

4. *German Signal System.*—The lack of political unity in Germany at the time when railroads were introduced affected many things unfavorably, and especially the signal system. M. M. von Weber, in his time, counted on some 60 railway systems over 90 different ideas to be given by signals, for which more than 1 000 different forms of signals were provided. A voluntary association—the Germany Railway Association—endeavored to bring order out of the chaos which existed in the railway system, and succeeded so well that even before the political union of Germany its standards were generally recognized, and the association itself comprised, not only all the railroads of Germany, but also roads in Austria-Hungary, Luxemburg, Russia, Holland and Belgium.

The signal code for German railways adopted by the Bundesrath, July 5th, 1892, to go into effect January 1st, 1893, contains 35 signal ideas, for which 65 forms of signal are allowed.

Characteristic of the German and still more of the Austrian signal systems are the continuous signals of the approach of a train. The English roads, with their heavy traffic, and also the French roads, adopted the principle that the road must always be in a condition as if a train were expected. But in Germany, in consideration of the many grade crossings, it was thought desirable, before a train left any station, to notify the next station and all the line employees (gatemen, etc.) between the two stations.

On the English roads each section of track is protected by a distant signal which is normally at danger, and is only placed at safety to allow the passage of a train, after which it is at once returned to the danger position. On the French roads, the track is normally clear, and is protected by a danger signal whenever there is anything to prevent the passage of a train, such as a grade crossing at which the gates are open, or when shifting is going on upon the tracks at a station, etc.

In Germany, before the introduction of electricity into railroad operation, masts with semaphores (or other signals) were so erected along the line that they could be seen from one another, and the signal of the departure of a train from a station was given from mast to mast to the following station. The semaphore, inclining obliquely upward, at the same time indicated to the engineer that his train was expected. As the location of the signals was generally chosen at crossings and other more or less dangerous points, this system afforded great safety, but required, on the other hand, a great many employees.

The numerous interruptions which this system of optical telegraphy was subject to on account of fog and bad weather led the German railroad companies very soon to adopt generally the apparatus used for electrical telegraphy—at first, dial apparatus, and very soon, the Morse apparatus. At present, on German railways there are few switchmen who are not familiar with the use of the Morse apparatus, and even many of the laborers are able to receive and send dispatches.

Since trains could then be announced electrically from station to station, signal masts along the line were abandoned, but in place of them an electric apparatus was introduced which announced the approach

of a train to the gate-tenders at important highway crossings and at other dangerous points, as well as to trackmen. This apparatus is the electric alarm of Siemens and Halske. It consists of a bell which can be sounded electrically from a more or less distant point, such as a station or a gate-tender's house. The signals are given either by a single stroke, or certain combinations of strokes, and the striking apparatus is designed accordingly. In Germany, the number of bell signals to be given is small, and the apparatus is, therefore, almost always inserted in an open circuit, and generally operated by magneto-electric apparatus, less frequently by dynamo-electric apparatus. In Austria, on the contrary, at every watchman's cabin on the line, not only simple bell signals are to be given, but other information is to be communicated to station and track employees, and the apparatus is therefore almost always inserted in a closed circuit, in order to avoid the necessity of providing every signal cabin with a source of current. It is thus possible to insert Morse apparatus in the line, which, however, is not impossible when induction apparatus is used. The various bell signals, in the case of a closed circuit, are given by breaking the circuit, for which automatic devices are frequently used.

Bell signals have recently been introduced on the Northern Railway of France, and on the Paris-Lyons-Mediterranean Railway. After the introduction of the electric bell signals, mast signals in Germany, and discs in Austria, were in general only used as distant signals for protecting stations, switches and crossings. The upward inclined arm, or the edge of the disc, or, at night, green light, meant all clear. The horizontal or normal position of the arm, or the full disc, or, at night, red light, meant "stop." This resulted in trains stopping often at a considerable distance away, without rear protection, and without knowledge as to the cause of the stop. Moreover, in case of fog, or bad weather, the engineer might not always be able to stop his train before reaching the signal, in spite of the penalty of dismissal, so that without backing up he would be without signals for his further guidance. This difficulty has been remedied in Germany, and first in Prussia, by placing the mandatory signal nearer the danger point, its position being indicated to an approaching train by a distant signal. The distant signals, which are generally connected automatically with the home signals, are round discs rotating about a vertical or horizontal axis, the disc or green light showing when the home signal is at

danger, and only the edge or white light when the signal is "all clear." Engineers may run by a distant signal at danger, the train being under control so that it can be stopped at the home signal.

Green light is chosen for "danger" at distant signals, because in Germany the rule is strictly adhered to that the engineer shall under no circumstances run by a red signal. Adherence to this rule has led to a peculiar development in the case of the mast signals. As already stated, the simple semaphore, in its normal danger position, is extended horizontally to the right, or, at night, shows red light; while safety is indicated by the arm pointing obliquely upwards to the right, or by green light.

Aside from the fact that in Germany, where trains run right-handed, the engineer is governed by the arm extended towards the right, and that this arm is raised instead of lowered into the all-clear position, this signal agrees entirely with the English semaphore. The case is different, however, at junctions, when it is necessary to place signals for the main and branch lines on one mast. In this case (in Germany) the mast has two or three arms and lanterns, over each other. The lower arms or lanterns are only used when a train is to be diverted from the main line. When the main line signal (upper) is at all clear or at danger, the lower arms are vertical, and show no light. By this arrangement, when the track is blocked, only one red light is visible at night. If the main line is all clear, one green light is shown ; if the first branch is all clear, two green lights, and if the second branch is all clear, three green lights above each other. Red light is never shown when any track is all clear.

These signals give no information as to the direction of the turn-out ; and more than three arms are not placed on one mast ; if there are more than three lines, additional masts must be erected.

The English practice regarding the arrangement of several signals on one mast differs therefore from the German in that the English place as many arms or lanterns above each other as there are diverging tracks, and that all of these lights show normally red. Only the one signal governing the all-clear track is placed at safety, or shows green light. While this is contrary to the German rule never to run by a red light, it serves as an excellent guide for the engineer, who (as in the case of the new French "direction signals") can tell at once from the number of arms or lanterns, not only the number of diverging tracks, but which

one is all clear. There is in this method no limit to the number of signals on one mast.

Position of the Signals.—The position of a distant signal, in order that the engineer may recognize it as intended for him, is not a matter of indifference. As a rule it is placed close to the track which it governs, and on the side of the engineer. In general, the signal need not be over 3 to 4 m. above the ground, so that the engineer of an approaching train may be able to see its position distinctly even in the worst weather or the thickest fog.

In France, great importance is attached to the position of the signal, and it is prescribed by the Minister of Commerce that if there should not be sufficient room for a signal between the tracks at the proper point, it is to be placed on an overhead footway.

The distance of a distant signal from the point to be protected depends principally upon the grade of the track, the speed of trains, and the number of brakes applied. In England, the distance has been generally 1 300 to 2 600 ft. (400 to 800 m.); in France, 2 000 to 2 600 ft. (600 to 800 m.). On account of increase in speed of trains without corresponding increase in number of brakes, it has been necessary in France to increase this distance to 3 300 to 4 000 ft. (1 000 to 1 200 m.) or in some cases even to 6 500 ft. (2 000 m.). In Germany, of late, a distance of 2 000 ft. (600 m.) has generally been assumed, in which a train may be stopped, from the point where the signal becomes visible (including time required to apply brakes); and on this basis the number of brakes is varied, according to the grade and the maximum speed.

Home signals are generally placed as near the point of danger as the local conditions admit.

If there is a facing switch at the entrance to a station, it is considered the point of danger, and in Germany the station signal is some 160 ft. (50 m.) beyond. If the track which the signal governs is occasionally used for switching, the danger point is taken as the furthest point so used.

If several parallel lines run into one station, the same number of entrance signals are to be erected side by side, each with its distant signal.

If trains on the same line enter the station by two or three different tracks which are to be designated by signals, the entrance signal mast has correspondingly two or three arms above each other.

Signals for departure from a station are in Germany, as a rule, only used when departing trains have to run over one or several facing switches. The switches and signals being connected, the position of the signal shows the station employees whether the switches are right for the departing train. The position of the starting signal must be such that it is in front of the longest train that it governs.

Starting signals can also be used in order to preserve the distance of a station between trains following each other. If two or more parallel lines lead out of a station in the same direction, the same number of starting signals are arranged side by side in a line at right angles to the tracks. If a track leading out of a station diverges in two or three directions, two or three arms are to be placed over each other on the same mast.

Part III.—The Train Staff System.

Before proceeding to the block system, so important for railroad operation, another mode of operating must be mentioned, which, indeed, requires no signals, but which can be regarded as the precursor of the block system. This is the "train staff" system, which takes its name from the fact that a staff is used, without which no engineer is allowed to run over the section governed by the staff. As in the block system, the road is divided into sections, there being a station at each end of a section. One staff is provided for each section, the different staffs being distinguished in form and color, and frequently having upon them the names of the two end stations of the section. By this system it is impossible for two trains to be on the same section at the same time.

If trains or engines are to follow each other in the same direction before the staff can be brought back, the following plan is followed: The engineer of the first train receives from the station agent a ticket stating that the staff will follow, and at the same time he is shown the train staff for the section. This is done in the case of every train leaving a station in a given direction before a train comes in from the other direction, except the last train, which carries the staff itself.

The box in which the "train tickets" are kept can, as a rule, only be opened with the aid of the corresponding "train staff."

Of course all trains must stop at the stations between sections.

The train staff system is considered in England as the safest method

of operating, even safer than the electric block system. The train staff is therefore not only still in use, but has also been much improved by the introduction of the electric train staff.

The electric train staff system, as used on the London and Northwestern Railway, consists essentially in having within a hollow cast-iron cylinder a number of train staffs of the same shape and color for a certain section of the road. These staffs can only be taken out one by one, through an opening in the top of the cylinder. The opening is electrically locked from the following station. Every train must therefore be announced to the following station. As soon as a staff is taken from the cylinder, electrical communication is broken between the two stations until the staff is placed in the cylinder at the following station, and not till then can the arrival of the train be telegraphed back. It is thus impossible for two trains to be in the same section at the same time.

Part IV.—Block Signaling.

W. F. Cooke's block system.
E. Clark; C. V. Walker; E. Tyer.
Siemens & Halske.
Lartige, Fesse and Prudhomme's electric semaphore.
Permissive block system. Spagnoletti.
Hall. Union Switch and Signal Company.
American Signal Company.
Black's block signal.
Concluding remarks.

The Block System.—Starting with the idea that every point of a railway was a point of danger which should be protected by signals, W. F. Cooke, in 1842, proposed to divide a road into sections, and to allow only one train or engine in a section and on the same track at the same time. At the ends of the sections there were to be signal stations with semaphore signals, and his idea was that the semaphore at the entrance to a section was to be a distant signal operated from the other end of the section and placed at "all clear" when the section was free. Since, however, a signal could not be operated mechanically from a distance of 2 to 3 miles, he placed needle-telegraph instruments at the ends of the sections, by which the signal operators could communicate

with each other, and thus make sure that a section was clear before allowing a train to enter it.

Cooke applied this system in 1844 on the Eastern Counties Road, but it was given up in consequence of an accident which, however, was not attributed to the system itself. In fact, this so-called "block system" had at first many opponents among the prominent English railway men, on account of the fact that it required several communications between the ends of a section, and so was a source of considerable delay to trains. They contented themselves, therefore, by providing telegraph stations at the entrances to tunnels and at similar dangerous places at which operators were stationed who could control trains and assure safety at these points.

It was soon found necessary, however, to return to Cooke's system, and at the present time the block system is recognized as the greatest safeguard in railway operation. The details of the system, of course, have been much improved since Cooke's day.

Next following Cooke's apparatus was probably the needle apparatus introduced by Edwin Clarke on the London and Northwestern Railway in 1853 and 1854. As a train approaches a signal station the operator signals to the station in advance by one stroke of a bell, and if the section is clear the operator there by the deflection of the needle to the right, gives the signal "all clear" if no train is in the section. When the train has entered the section, it is announced to the operator at the station in advance by two strokes of the bell, upon which the latter deflects the needle to the left and signals "line blocked," in which position the needle remains until put at "all clear" for a following train. If the circuit is interrupted, as, for instance, if a train is stalled and the conductor cuts the wire, the needle takes a vertical position. The disturbances of the needle due to atmospheric electricity, which were originally felt, are prevented by the use of "Varley's safety needles."

In the meantime, in 1852, C. V. Walker had introduced on the Southeastern Railway a signal system in which trains were signaled by strokes of a hammer upon a bell. Generally, there were but three signals, namely:

One stroke, departure of a train for London (up train).

Two strokes, departure of a train from London (down train).

Three strokes, arrival of a train.

The strokes were caused by pressing a button. Every signal was acknowledged by repeating to the sender. This audible block system was in 1855 perfected by the addition of a visible signal, consisting of a miniature double-armed semaphore framed under glass and hung on the wall of the signal station, and works quickly and reliably. One arm of the semaphore is red and shows the signal received from the adjacent station, while the other is white and shows the signal given from the local station. Two spring keys, one red and one white, connect the circuit with a battery, and serve to give the bell signals and to set the semaphores. Pressing the white key sets the red arm at the adjacent station and the white arm at the local station at "line clear," while at the same time the bell is struck; pressing the key again strikes the bell, but does not affect the semaphores, while pressing the red key brings both arms back to "line blocked." The inventor's object was to devise a signal which should be the counterpart of the outdoor semaphore signals given to trains. With Walker's apparatus the block system was operated with the greatest strictness.

A patent was also granted in 1852 to Tyer for a signal apparatus based on the same ideas as Walker's. The older instruments have a black indicator for arriving trains, and a red indicator for departing trains; while in the newer instruments the signal is given by a miniature semaphone with a red and a white arm. While, however, Walker used two wires, one of which operated the visible and the other the audible signals, Tyer succeeded in giving both signals with one wire, by adding a ringing key and a relay. Tyer's apparatus is specially recommended by the Board of Trade, and to this, as well as to the fact that it requires but one telegraph wire, it owes its extended use on English and also on French railways.

The block signal systems thus far described are not dependent on the corresponding outdoor signals along the line, but are simply telegraphic apparatus which has no relation to the outdoor signals except that they are under the oversight of one and the same watchman.

In Germany, owing to the fact that from the beginning every station had been equipped with telegraph apparatus for announcing trains, the introduction of the block system was less difficult than elsewhere. At present, Morse printing instruments are used almost without exception for this purpose, possessing the advantage of preserving the

messages. For the introduction of the block system it was thus only necessary to abandon the time interval system previously used, and to require trains to follow each other only at a distance of a section. The fact, however, that all previous block systems were open to the objection that the signals received by the signal operator had to be transferred by him to the outdoor signals, led Chief Engineer Frischen, of the firm of Siemens & Halske, in Berlin, to devise a block signal apparatus in which the outdoor signal was interlocked with the block apparatus in such a way that it was impossible for the operator to set an outdoor signal at "all clear" as long as the section beyond was blocked. The block signal apparatus consists of a cast-iron box hung on the wall of the signal house, and in which are two small openings in which a white or a red disc is visible, the former signifying "all clear," the latter "stop." Under the openings are arrows showing the directions to which the openings refer. Beneath is the mechanism for setting the outdoor signal. "All clear" is shown by a white disc, and "line blocked" by a red disc. The discs are operated by means of signal keys, besides, which, however, there are so-called ringing keys, for indicating by an alarm the approach of a train. The current is generated by a Siemens' machine giving an alternating current for operating the block signals, but which is also suitable for giving the continuous current necessary for the alarm. The alarm, as well as the block signals, require but one line wire for both directions.

Every change in the position of the block signal disc is accompanied by an alarm inside the cast-iron box, while the approach of a train is indicated to the signal tender, both audibly and visibly, by an alarm provided with a disc signal, so that he may at the proper time set his track signal to "all clear." The alarm may also be used to communicate various other signals.

The locking of the signal lever is effected by a lock pressed upward by a spring under the signal key.

Each pair of block signals connected by a wire are then so arranged that they must always give opposite indications. A signal-man who causes the white disc to appear at the station behind him, and thus unblocks the section changes his own disc to red, and thus blocks himself. He cannot send back the current necessary to unblock the section till he has set his out-door signal at danger, and after unblocking the rear section he cannot set his out-door signal to "all clear"

until the following section is unblocked by signal to him from the station in advance.

Since each change of a block signal requires 21 alternating currents, these signals are completely independent of the effects of atmospheric electricity. Moreover the use of the induction apparatus overcomes all the difficulties connected with the use of batteries, so that the Siemens and Halske block system apparatus may rightly be called the most complete and reliable of its kind.

A peculiar block signal was proposed by Lartige, Fesse, and Prudhomme, which has been used since 1874, at first on the Northern Railway of France, and afterward, on the other French railways. It consists of a signal mast carrying at the top two signal arms, one for each direction; these arms carrying also the lenses for the night signals, one red and one green. The green glass is added in order to distinguish the red light of this signal from that of the disc signals. All the glasses are illuminated by a single lantern, the red glass by direct light, the green by reflected light. Each mast carries also half way up two small arms painted yellow, which are not for the engineer, but only for the information of the signal operator. At the foot of the mast are fastened boxes, two for each direction, containing the operating mechanism and alarms, each box being numbered and showing also the track which it governs. The peculiarity of the apparatus consists in the fact that the signal-man himself directly places the arm at the preceding station in the all-clear position. Each signal is also provided with a distant signal, a round or square disc, so that a train may, if necessary, be stopped at the home signal, thus protecting a train standing at that point. The distant signals are operated by hand. If the two sections on either side of a signal mast are clear of trains, all the signal arms hang vertically, in conformity with the French rule that no signal is shown if the track is clear. Boxes No. 1 show behind little openings white discs with the notice—

Track $\left\{\begin{matrix} \text{I} \\ \text{II} \end{matrix}\right\}$ all clear towards.....

Boxes No. 2 also show the white discs, with the following notice:

Track $\left\{\begin{matrix} \text{I} \\ \text{II} \end{matrix}\right\}$ open to.....

If a train or locomotive approaches a block station, the signal-man first covers it by the distant signal. As soon as it has passed the signal mast the operator goes to box No. 1 for the track on which the

train is running, and makes about half a revolution of the crank. This sets the corresponding signal arm horizontal, and at the same time the alarm is sounded at the station in advance; the small arm at this station takes the horizontal position, and in box No. 2, connected with it, the red disc is shown with the notice—

Track { I / II } closed to.....

The rear station receives at once the acknowledgment of the signal by the stroke of a bell, and the appearance of a yellow disc with the words—

Track { I / II } train announced at.....

As soon as the signal-man at a station at which the approach of a train has been thus announced by the appearance of the small arm sees that the train has passed his distant signal, he places the latter at danger. As soon as the train has passed he protects it by the danger signal, and by means of the crank in box No. 2 he drops the small arm at his own station, and the main block signal at the preceding station.

Permissive Block System.—In this system a horizontal position of a semaphore commands an immediate stop. If an engineer stops his train, however, and the all-clear signal is not given from the advance station within five minutes, the operator can allow the train to enter the blocked section. The engineer, however, must make sure, by observing the track closely that he incurs no danger, and must proceed so slowly that he is able to stop his train in safety should any obstruction appear. He can resume the ordinary speed only after passing an "all-clear" signal.

Spagnoletti, the telegraph inspector of the Great Northern Railway, has constructed an apparatus in which the signals are given according to the principles usual in England. For each direction there are two indoor signals, the upper showing the signal received and the lower showing the signal given. Instead of dials or miniature semaphores, however, the upper opening shows in its normal position a red disc with the words "lock on," meaning that the signal is locked, while the lower opening shows a green disc with the words "train arrived." The operator inquires of the following station by means of bell signals whether the line is clear and if this is the case the operator there replies by pressing a key which shows at his own lower signal

and at the upper signal of the preceding station a white disc with the words "line clear," and at the same time the track signal at the latter station is unlocked, so that it can be placed at safety. This is done by pulling a lever. As soon as the train has passed, the lever is returned to its former position, covering the train by the danger signal: this, however, not only locks the lever, but shows on the upper opening of its own station and the lower of the following station a red disc marked "train on line." In this position neither of the two operators can alter any signal, since the rear outdoor signal, by being placed at danger, breaks the circuit; so that it cannot be placed at safety, thus admitting a following train to the section. The circuit remains open until the train reaches the following station, when it closes the circuit by means of a track instrument, and at the same time shows at this station in the lower indoor opening a green disc with the words "train arrived," and in the upper opening at the preceding station a red disc with the works "lock on." The operation can then be repeated. Only one line wire is required for this system, including the bell signals, and the details are so arranged that any interruption in the line or any failure of any part of the system brings the signals to the danger position.

This method forms the transition to the automatic block systems. In general, the sentiment in England and the rest of Europe has not been particularly favorable to automatic systems which dispense entirely with manual aid, principally because such systems themselves require in any case continual supervision, in order to ensure their reliable action.

In the case of Spagnoletti's apparatus just described, the signal "train arrived" is operated by the first wheel passing over the track instrument, and it may therefore happen that a train may set this signal and yet come to a stop before it has completely passed the track lever. To avoid the danger which might result, each operator is required to satisfy himself particularly on this point before giving the "all-clear" signal to the preceding station.

Automatic Block Systems.—Although in Europe we have hesitated, thus far, to introduce entirely automatic block systems, in America they have been introduced without hesitation and apparently with good results. Hall was the first to introduce such a signal, which in its newest and much improved form has been extensively used on the

New York, New Haven and Hartford, the Boston and Albany, and other roads. The signal itself is held in its normal position by an electro-magnet in a closed circuit. If the circuit is broken, the disc falls and shows red. Distant signals are similar to home signals except that the disc is green. The breaking of the current is effected by means of a wire circuit with a weak current, in which a second electro-magnet and two track instruments are inserted. One track instrument, the so-called "block" instrument, is at the entrance of a block section and is connected in circuit with the battery at the other end of the section and with the electro-magnet. When the first wheel of a train passes over this instrument, it breaks the circuit and both armatures fall, the signal going to danger.

Some 1 500 to 2 000 ft. (450 to 600 m.) beyond the end of the block section is the "all-clear" instrument, which differs from the stop instrument in that its normal position corresponds to open circuit, and that when struck by a wheel, instead of changing its position at once, it does so only after a time sufficient to allow the passage of the longest train at the slowest speed, by means of a compressed air cushion.* This instrument closes the circuit again and clears the section.

The "block" instrument of any section is beyond the "clear" instrument of the preceding section, so that a train entering a section is protected before the signal at the entrance of the preceding section is cleared.

The compressed air cushion of the "clear" instrument is said to be the weakest point in this block system. Any failure in the current or crossing of wires brings the signal at once to danger. Breaking apart of trains and breakage of rails are not shown by the system, but this could be effected by using the rails as conductors. This, however, is not recommended, since the rail circuits for considerable distances do not operate uniformly and reliably enough. In general, however, the use of the Hall system is strongly recommended, and is particularly suitable for long block sections.

Very similar in working is the electric automatic block system of the Union Switch and Signal Company, in Pittsburgh. The sections are from 1 000 to 1 500 ft. (300 to 750 m.) long, and at the ends are signal masts. At the top of each mast is the home signal, the normal posi-

* This does not quite correspond with the instrument as now constructed.—*Trans.*

tion of the arm being horizontal, or at danger, or at night showing a red light. With short block sections and frequent trains, there is also a distant signal arm for the second section ahead, the end of this arm being notched, as in the English distant signals, to distinguish it from the local home signal. The lantern of the distant signal is normally green, indicating caution, while both signals show white light when at safety.

The signal arms are moved by compressed air, as already stated, controlled by electricity. While the Hall system uses a separate wire for this purpose, the Union Switch and Signal Company uses the rails for conductors. The rails are electrically connected, except at the end of a block section, where there is an insulating joint. It has been found unnecessary to insulate the rails from the ties. A battery at the farther end of the section sends a weak current through the rails, which, at the near end of the section, are connected by the two wires of the electro-magnet which operates the signal. Any pair of wheels in the section short-circuits the current, the armature of the signal electro-magnet drops, and the signal goes to danger, the corresponding distant signal going to "caution." By a switch on the arm of the local signal, the distant signal for the section in advance goes at the same time to caution, while its corresponding home signal remains at safety. Any failure of any part of the apparatus results in the corresponding signals all going to danger. Breaking apart of trains and fractures of rails are at once indicated. If there are switches in the section which are included properly in the circuit, the block signal will only indicate "all-clear" when the switch is properly set and no wheels are upon it.

The method of operating signals by means of bellows, introduced by the American Pneumatic Signal Company, has also been applied to the operation of automatic block signals in a manner as ingenious as simple. When a train enters a section the first wheel, by means of a track instrument, acts on the bellows and sets the signal at danger, at the same time clearing the signal in the rear. The bellows is far enough in front of the block signal that the engineer can see the signal go to danger before passing it, and thus know that his train is protected. This, however, has the serious objection that if a train should stop just as the first wheel had passed over the track instrument, it would not be protected at all.

Black, in his block system for the New York elevated roads, has made use of the principle employed in Hall's electric system, namely, that a train must be protected by a forward block signal before the rear block signal is cleared. In Black's system, however, the operation is entirely mechanical. The transmission of the motion by rods requires the block sections to be short, and the signals are therefore only about 1 100 ft. (335 m.) apart. The rods are supported upon rolls between the rails, and are protected by wooden casing against the sun and against disturbance. Powerful track instruments in the form of levers connected with toggles are operated by the wheels, and carry the motion to the rods. Shocks are avoided by inserting strong spiral springs. A train length beyond the signal mast (one engine and five cars) is the first track instrument which sets the danger signal for the section in advance, and just beyond is the second track instrument which clears the signal for the rear section. In consequence of this overlapping, the signal rods are longer than the length of a section, sometimes up to 2 700 ft. (825 m.). In order to provide for the changes of length of such long rods, due to temperature, the oblique slot at the end of the rod, which effects the change of the signal, is lengthened at both ends parallel with the motion.

The capacity of the roads equipped with this block system is very large. The signals being placed 1 100 ft. (335 m.) apart, and the speed of trains 16 to 17 miles per hour (26 to 27.5 km.), it is possible to have trains follow each other at intervals of ¾ of a minute. This simple system is very inexpensive and yet thoroughly reliable. During the three days of the Columbus celebration, October 10th–12th, 1892, the elevated roads of New York carried 2 921 864 passengers; and on October 12th, alone, 1 075 537 passengers.

In one day, on the Third Avenue elevated road, 8.5 miles long (13.6 km.) the traffic amounted to 55 000 car-miles (87 000 car-km.), and 1 200 engine-miles (19 000 engine km.).

Closing Remarks.—On main lines the block system is now indispensable for safe operation. The choice of a system, however, depends largely upon the character of the traffic. If trains of different length and speed run over the same line, and if the length of stops at the different stations cannot be fixed beforehand with accuracy, the use of the Morse writing telegraph is to be recommended, especially because it preserves permanently the dispatches sent, and thus affords a basis

for providing for further irregularities in time. An interval of five minutes or less between trains is only possible when trains run with nearly the same speed. In such cases the use of writing instruments takes too much time, and it is necessary to resort to methods such as have been described, by which trains are signaled quickly, or to automatic systems.

Part V.—Interlocking Apparatus.

Introduction.

English interlocking apparatus. Saxby & Farmer.

German interlocking apparatus. Max Jüdel & Co.; Rüppel's system; Büssing's patent; Schnabel & Henning.

Fundamental principles of German interlocking. Locking the route; locking apparatus; protection of isolated switches; slotted signal.

Differences between English and German interlocking apparatus. Switch locking; significance of the distant signal; safety switches; detector bars.

American interlocking apparatus. Saxby & Farmer; St. Louis Bridge and Tunnel Co.; Westinghouse's switch and signal interlocking.

Hydraulic pressure apparatus. Bianchi & Servettaz; Haniel & Lueg.

Closing remarks.

Introduction.—The danger which arises from the fact that at a turnout the signal may not agree with the position of the corresponding switches led the English roads, as early as 1846, to concentrate at one point (by means of rods, etc.) the levers operating the switches and signals, so that they could all be operated by one man. Since, even by this method, however, mistakes were not impossible, Saxby, in 1856, conceived the idea of interlocking the switches and signals in such a way that it would be impossible for the operator to set a switch contrary to the signals, or to clear simultaneously two interfering tracks. This idea led to the development of what is known as the interlocking system. According to this system, as soon as (or before) a given lever is thrown, the motion of certain other levers is rendered mechanically impossible. This is effected by adding to the simple lever apparatus a special device, consisting in the main of a movable locking bar,

moving parallel to the row of levers, and provided with the necessary locking pieces. The mechanism is designed on the basis of a given mode of operating the tracks, and a corresponding locking table is prepared, showing positions of the switches and signals which are incompatible or dangerous. The locking pieces are then arranged so as to conform to this table.

This interlocking system has since been found indispensable in governing the entrance and departure of trains at stations where the traffic is heavy.

English Interlocking Apparatus, Saxby & Farmer.—The interlocking apparatus of Saxby & Farmer is distinguished by its simplicity and its solid construction, and it is sufficient in general for English requirements. Its use is limited by the legal requirement in England that facing and trailing switches shall not be operated by means of rods at greater distances than 540 ft. (165 m.) and 900 ft. (275 m.), respectively. In consequence, the switches operated from one point are concentrated within a space which can be easily overseen and watched from the central point. This area is protected in all directions by signals, resembling a citadel, in which the operator—a reliable man, trained from youth by many years' service—holds absolute command. This method has been entirely satisfactory on English roads. Attention has since been directed to a feature which this system does not possess, namely, the interdependence of the interlocking system with the block system.

German Interlocking Systems.—In Germany less reliance is placed upon the signal-man stationed at the towers, since, notwithstanding the interlocking of the switches and signals, he can give an improper or unaccustomed signal to an expected train, and thus bring it in upon a wrong track, where the station employees do not want it, or can allow it to enter before the station-master is ready for it. The Saxby & Farmer apparatus, therefore, which was introduced in Germany in 1870, did not fully satisfy the needs of German roads. The firm Max Jüdel & Co., in Brunswick, builders of railway signal apparatus, at first imitated the English interlocking apparatus, but finally their eminent engineer, H. Büssing, developed it to conform to German requirements. At present this company builds interlocking apparatus after Rüppel's system and Büssings' patents.

In 1874, Th. Henning of the firm of Schnabel & Henning, at Bruch-

sal, showed at the Vienna Exposition an interlocking apparatus of his own construction, and since that time these two and some other German firms have taken the greatest pains to bring their interlocking apparatus to the highest possible degree of perfection.

Fundamental Principles for German Interlocking.—In consequence of the fact that the management of the traffic is separated from the duties of the operator in charge of the levers, and in order that the station-master, who oversees this traffic, may have exclusive control of the entrance and departure of trains at the station, special interlocking devices are applied between the offices of the station-master and the various interlocking towers of the station, which are known as "station blocks" (*Stationsblockwerke*), "signal locks" (*Signal Verschlusswerke*), "electric slot apparatus," etc.

These appliances led to the idea of making the station-master and the signal-operator interdependent, in such a way that before the passage of a train by a tower—

(1) The switches to be passed over must be set and blocked by the operator.

(2) The signal for the train must be cleared by the station-master. And after the train has passed—

(3) The signal must be put at "danger" behind the train, by the operator.

(4) The switches must be freed for other operations by the station-master. This cannot be done till the train has completely left the protected area.

Locking the Route.—A further innovation in German interlocking is locking the entire route of a train through a yard. Formerly, if a signal was cleared it locked the switch to be passed over in the proper position. This had the objectionable feature that as soon as the signal was put back at danger, the switch was unlocked ; while it is often very desirable that after the signal is put at danger, behind a train, the safe position of all the switches to be passed should be assured till it is certain that the train has passed them all. This led to the introduction of "route levers" which are properly interlocked. This renders it unnecessary to hold the signal lever in the "all-clear" position, in order to lock the switches. On the contrary, all the switches over which the signal gives right of way are locked by the station locking apparatus, without making it impossible for the

operator at the tower to throw the signal to "danger" at any time.

Electrical apparatus was formerly exclusively employed for controlling the levers in the towers at the ends of the station from the offices of the station-master. Lately, however, these have been largely replaced by mechanical apparatus, and electrical locks only retained in connection with such sections as are equipped with Siemens & Halske block apparatus, or in cases where the station is a considerable distance from the levers.

In the newer mechanical locks, double wires are invariably used, which, besides being all that could be desired with respect to simplicity of construction and ease of repair, are, moreover, as a rule, cheaper than electrical locks up to distances of about 4 000 ft. (1 200 m.).

Locking Apparatus.—The locking apparatus in the station (or sometimes on the platform) is operated generally by a crank. Each crank serves for controlling two directions or routes, being connected with a locking bar in the interlocking tower. When the crank is in the intermediate position, this bar cannot be moved; if the crank is turned to the left, it frees the locking rod for one route (*i. e.*, allows the all-clear signal to be given for this route, and locks all switches which the train is to pass over); if turned to the right, it frees another route. This differs from former arrangements in that here it is not the signal lever which is freed or locked, but only the locking bar or the lever by which the latter is moved. Whenever the station crank is turned, the signal operator is informed by an audible and a visible signal, and he is thus directed to clear or to block some given route.

The interdependence already existing between the various levers of the interlocking apparatus of the tower is generally repeated in the locking apparatus at the station, so that the station-master can never free two interfering routes. A further interlocking has also been added such that when the signal has been given for a train to enter by any given track, it is impossible to again give the all-clear signals for that track from any direction whatever until a departure signal for this track has been given and then removed.

Protection of Isolated Switches.—A road is not always in a position to protect a station or junction by erecting at once a special interlocking plant. According to the laws governing the operation of main lines

in Germany, however, signals for the protection of switches, which in ordinary operation are facing points, are obligatory. The signals must be so arranged that the signal for any track cannot be cleared until the switch is set for that track, and the switch must remain so set as long as the signal is clear. Here, also, the object has been to relieve the switchman of the duty of setting the signal, placing this in charge of the station-master. For this purpose, switch-lock discs are used, which are inserted in the double wire by means of which the station-master from his office or from the station platform sets the entrance signal for the station. The disc has a widened rim by means of which either directly or by an intermediate latch, it engages in recesses of a locking bar connected with the switch lever in such a way that the switch can be set at will as long as the signal is at "stop," while the signal can be cleared only when the switch is set for the proper track. Setting the signal at "all-clear" locks the switch in this position.

Slotted Signal.—Even before it was proposed to interlock switches and signals, a device had been introduced in England by which a signal could be cleared only by the concordant action of two signal-men stationed at different points. This device is found principally in cases where signal towers are only a short distance apart, so as to make, for instance, the departure of a train from the area governed by one tower dependent upon permission given from the following tower. The device consists principally in having one or more slots in the rod which works the signal, in each of which slots a pivoted lever works, each lever holding the signal at danger by means of a counterweight. The signal can be cleared only when all the counterweights are raised; as soon as one counterweight falls, the signal goes at once to danger. It is thought that Saxby first conceived his idea of interlocking from this apparatus.

Saxby & Farmer afterwards constructed an apparatus on which the more distant signal-man controls the signal electrically. This is called the "electric slot signal," although in this case there is no slot.

In Germany, slot signals are now used quite widely, in order to secure interdependence between groups of switches operated from different points, with respect to certain switches and signals. By such means all the switches for a certain route operated from one point can be locked, and at the same time the all-clear signal for this route given in the adjoining section.

Differences between English and German Interlocking Apparatus.—In England, as already stated, the signal-men in the towers are quite independent, while in Germany they only do the bidding of the station-master. It cannot be denied that the idea of concentrating the entire superintendence of the traffic in the hands of a capable official appears very desirable, but it must be acknowledged that if the duties of the official confine him to an office in the station building or to a particular place on the platform, he cannot always himself see the condition of things at the ends of the station or yard before giving orders for the entrance or departure of a train. He must therefore rely more or less on information given him by signal-men at those points. The signal-man, as soon as he receives from the station the order to give a certain signal, must satisfy himself that the route to be followed by the train is really clear before obeying the order. Now, since the obstacles in the way of a train are generally about the switches at the end to the station yard, it follows that the most important point for insuring the safety of station service is not at the center of the station, but at its ends. Moreover, mistakes on the part of the station-master, or misunderstanding on the part of the signal-man, are not impossible, even with the most perfect system, and have been the cause of accidents.

If the work to be done daily at a station equipped with interlocking apparatus is laid out systematically and permanently, and the traffic is regular, the signal operator, if he follows the schedule, cannot well open a route that is not desired by the station-master, and even if he should by mistake do so, the engineer of an approaching train would be able to tell from the signals that his own track was not clear and would come to a stop. The danger that a signal-man might allow a train to enter a track already occupied may be easily obviated by arranging the main tracks in the station so that that they form a block section, like the main line beyond the station. No train will then be allowed to enter the block section within the station till the previous train has left this section and its rear signal has passed the further tower.

Finally, it must be acknowledged that if trains follow each other at short intervals, delays will be occasioned, if it is necessary, before admitting them for the signal-man to communicate with the station, so that it is better to concentrate the responsibility in the hands of the

signal-man. A simple telegraph connection is sufficient to communicate special messages from the station-master to the signal-man.

An objection frequently urged in Germany against the Saxby & Farmer apparatus is the large number of levers used. When we remember that, for instance, Max Jüdel & Co. build interlocking apparatus in which a station at the crossing of two double track roads with two switches, two double armed entrance signals, besides two distant signals and four starting signals, are operated by only four cranks (wires being used to throw the switches), it seems worth while to examine the causes for the large number of levers in English interlocking apparatus.

Switch Locking.—In this examination the first striking point is the locking of each switch by a special lever. In England it is considered absolutely necessary to ensure the full contact of the tongue of a facing switch with the fixed rail by means of a special slightly wedge-shaped bolt which is forced into a corresponding hole in the rod connecting the two movable points. The lever of this lock takes the place of the switch lever in the interlocking apparatus. This lock is also generally provided with a detector bar, which prevents the lock from being withdrawn as long as a wheel is over this bar. This doubles at once the number of switch levers.

In Germany, as already stated, the locking of isolated switches by means of the signal wires is generally introduced, but the locking of switches by means of special wires and levers in the towers is only introduced in exceptional cases. In place of them there are special throwing devices at the switches called "point locks" or "switch locks" which are intended to assure the signal-man that in throwing his switch lever he has actually brought the movable point into perfect contact with the fixed rail. This switch lock is intended to be unaffected by small temperature changes of length in the lead-out, or by the unavoidable lost motion occurring to a greater or less extent in the transmission mechanism. These devices, which throw the switch and at the same time lock it in its new position, have thus far proved thoroughly satisfactory. It must be remarked, however, that almost all the interlocking systems in Germany are of recent date, and that consequently the natural wear of bolt connections and other transmission mechanism has not yet taken place to a serious extent. This wear, however, may take place unnoticed to such an extent that if a

slight resistance is offered to the throwing of a switch, it may be possible to throw the lever completely over without ensuring perfect contact of tongue and fixed rail. It must be further recognized that the lateral pressure of cars passing over a switch may gradually result in the point not being in contact. Attention is therefore now being directed to the idea of providing some means, independent of the switch-throwing apparatus, by which the signal-man may be assured that in distant switches close contact is secured.

Significance of the Distant Signal.—Another circumstance which leads to again doubling the number of levers in English apparatus, is the different meaning of the distant signal. In Germany, the distant signal simply calls attention to the position of the home signal, and as both must always be in the same position, they may be operated by the same wire. In England, on the contrary, the distant signal is an independent stop signal, under whose protection, if at danger, the train proceeds. If the home signal is then cleared, the distant signal remains at danger, and not only protects the train against a rear collision, but also locks the proper switches. The interlocking of the distant and home signals is such that though the latter may be cleared, while the former is at danger, the reverse can never occur.

In Germany it is considered unnecessary to protect a train by the distant signal, but dependence is placed upon a strict adherence to the block system. There have been instances, however, of more or less serious rear collisions between a train stopping before the home signal and a following train.

Safety Switches.—The fact that special switch locks are not used in interlocking has enabled German engineers to make the switches so that they can be run over as trailing switches even when set for the wrong track (so-called "safety switches"), without injuring the interlocking apparatus or causing the tongues to assume an intermediate position, clear of both fixed rails. This is effected by making the switch rod connecting the points discontinuous and using the "point lock" already referred to. When a switch is thrown, the operation is as follows: the motion of the rod first moves the point which is not in contact, at the same time unlocking the other point; both points then move together till the former comes to contact, when it is locked, while the motion of the other point continues. If the switch is run through trailing, when wrongly set, the motion is caused by the free

point being forced aside and is transmitted by the rod, the procedure being the same as just described. In order that the interlocking apparatus may not be injured, a connection is introduced between the lever and the switch rod, which is rigid when the switch is thrown in the usual way, but which becomes detached with slight resistance when the switch is run through backward. At the same time the proper signals are locked and the signal-man notified.

Detector bars, which prevent a switch from being thrown while a train is upon it, are seldom used in Germany, the position of the switch being considered sufficiently assured by the locking of the signal lever or of the switch lock lever. It does, however, excellent service if suitably constructed, in all movements which must be made within the interlocked area without requiring or perhaps permitting the operation of a signal or route lever.

American Interlocking.—The Saxby & Farmer apparatus was introduced in America in 1873, and used with it, the English method of operation, consisting principally in separating the announcing from the despatching of trains, this method having been in general and very extended use in America before the introduction of interlocking.

The Saxby & Farmer apparatus is still in use at many large stations, junctions and crossings, but the practical American mind has introduced many simplifications, consisting mainly in placing movable pieces on the locking bolts, which effect a certain interdependence between special locks, and preserve this relation in different positions of the locks.

The considerable force necessary to throw switches by means of rods (pipes) or wires, and the necessity of having a number of signalmen in the towers at the same time, led the Americans to replace manual power, so far as possible, by other forces, mainly hydraulic pressure and compressed air.

The attempt was made on a large scale in 1883, to employ hydraulic pressure for operating the extended plant of the St. Louis Bridge and Tunnel Company. This system covered a length of nearly 3 miles (4.5 km.) of double track, with three towers and about 28 miles (45 km.) of yard and side tracks, with a corresponding number of switches and signals, and operated, in 1887, 131 trains daily. The experiment did not lead to the expected results, and the plant was altered by substituting compressed air as the power, using hydraulic pressure only to

operate the valves. This new plant, designed by Mr. Wuerpel, offers many points of interest. It is described in the *Railroad Gazette*, 1889, page 90. The three towers contain together 108 levers, of which 80 are in the tower at East St. Louis. These levers operate 138 switches and signals. The comparatively small number of levers is due to the fact that by a special device certain signals (as many as nine) can be operated by one lever. This is effected by placing valves in the water pipes leading from the tower to the signal cylinders. These valves are so connected with the switch mechanism that when the signal lever is thrown, the water is always admitted to the signal cylinder which corresponds to the switch in question. The operation of this plant requires the minimum of force. In the East St. Louis tower, one man operates the 80 levers, in eight-hour shifts. The track movements, when completed, are electrically announced at the tower and indicated on a miniature plan of the yard, with movable switches whose positions correspond with those of the actual switches. The electrical contact is made at the point of the switch. The entire apparatus, except that for operating the indicator, is contained in underground conduits and thus protected from injury in case of derailment.

The Union Switch and Signal Company.—By a great expenditure of money, time and labor, this company has succeeded in constructing an interlocking system after the ideas of Westinghouse, which satisfies in the highest degree all the requirements which can be be made upon a safety interlocking apparatus. Its operation, especially, requires little power, it is very compact, convenient in arrangement, and the lead-outs can be placed underground or in any way desired, if necessary outside the track area. The plant is costly, however, and therefore only suitable for large installations. An illustrated description may be found in the *Scientific American* for May, 1891, page 273. The signals and switches are operated by compressed air at a pressure of not less than 2.8 atmospheres. The valves at the switches are operated by hydraulic pressure, those at the signals by electricity. The throwing apparatus, instead of the usual levers and rods, consists of a series of horizontal shafts in a horizontal plane, which are rotated by cranks. The motion of the shafts is limited by electric stops. At the ends of the switch shafts, are three way cocks through which passes the water which operates the air valves at the switches ; while from the ends of the signal shafts, the electric current is sent to operate the air valves at

the signals. Each switch is thrown by means of a compressed-air cylinder, whose piston, in being thrown, first unlocks the switch, then throws it and then locks it again by a locking bolt. Connected with the apparatus is a fouling bar, to prevent the switch from being thrown under a train. The locking bolt, when in its final position, closes a circuit which in the tower effects the release of the lock of the switch shaft. The locking of a signal shaft is effected by a current, which is broken as long as the signal arm is in the all-clear position. The interlocking apparatus in the tower is peculiar. The shafts which serve to throw the switches and signals are insulated by rubber coverings, upon which are strips of platinum, and between the shafts are springs for closing the circuits, so arranged that the sending of the current for a given signal is made dependent upon the previous proper setting of all the switches involved. Throwing any switch out of position would break the circuit and bring the signal to danger. When a signal is cleared, the cranks of all the switch shafts involved are mechanically locked by a special locking bar. Before the signalman is a model of the yard, with movable switches which follow the motions of the actual switches as soon as the latter are fully thrown. Track circuits are also arranged, by which the operator can see which tracks, if any, are occupied by cars. Little covered windows with the number of the route, together with an electric bell, announce automatically the approach of each train, as well as the route which it takes.

Bianchi & Servettaz.—Notwithstanding the unfavorable results attained in America with the use of hydraulic pressure for operating the switches, Messrs. Bianchi & Servettaz have recently brought forward a signal system which they have tried on the Italian Mediterranean road, and which has also been introduced tentatively in Germany by the firm Haniel & Lueg, in Düsseldorf. In order to prevent freezing, the water is mixed with 40% of glycerine, and is used under a pressure of 50 to 60 atmospheres. The pressure serves not alone for transmitting the power, but also for effecting return signals from the tongue of the switch to the operating lever. This not only informs the operator accurately of the position of the switch at any time, and of its movement when being thrown, but is arranged to prevent him from clearing a route for which the switches are not all properly set.

While in the Italian interlocking apparatus the switches are firmly locked in position when thrown, the above-named German firm has made them as safety switches, so that they may be run through trailing, even when set for the wrong track. These safety switches differ in their action from those previously described in one important respect, viz., that, after being run through the points they again assume their former correct position instead of being thrown over. This system has yet to be exposed to the test of practical operation.

Concluding Remarks.—According to the report of Messrs. F. Büte and von Borries, who were commissioned in the spring of 1891 by the Minister of Public Works to make a tour of inspection in America, these engineers saw at the Jersey City Station of the Pennsylvania Railroad three passenger trains leave the train house almost at the same time and proceed on the same track within 1¼ minutes, each train receiving its complete signals, and safety of operation being completely assured.

If we are to judge of the perfection of an apparatus by its results, we must undoubtedly award the palm to the American interlocking systems, especially that of the Union Switch and Signal Company.

With the English interlocking system it has not been possible to attain a train interval of less than two minutes, on account of the greater power necessitated by the use of rods for transmission; while in Germany this train interval must be considerably increased in consequence of the complicated process of announcing trains.

With regard to the objections to the various methods of leading out, and which in the case of rods (pipes) and wires (besides the changes of length due to variations of temperature) consist particularly in the yielding of some of the intermediate supports, resulting in binding and difficulty of operation, we may here specially direct the attention of railroad engineers to the use of compressed air. As compared with hydraulic pressure, compressed air has the advantage that it may be used at a pressure of only 2.8 atmospheres, while the former requires a pressure of 50 to 60 atmospheres. Moreover, the air may be allowed to escape freely anywhere after being used, while the use of hydraulic pressure requires a special return pipe.

PART VI.—MISCELLANEOUS SIGNALS.

Switch signals in general; Max Jüdel's; Backofen's; Cumming's.

Latowsky's steam alarm.

Drilling or shifting signals in general; drilling clock; French indicators; Hattemer's track describer.

Train signals; bell cord; continuous air brakes; electric train signal of the Eastern Railway of France; Rayl's emergency signal; Griggs' train signal; Pennsylvania Railroad signal.

Signals for help; use of the telegraph line; Austrian signal for help; Siemens & Halske's signal.

Switch Signals.—Since the introduction of interlocking, switch signals have lost much in importance, for the interlocked track signals indicate with certainty to the engineer and others the position of the switches. In Germany, therefore, no steps have been taken of recent years towards securing uniformity in switch signals. By the new signal regulations it is prescribed that switch signals must indicate by day or night, by their form, whether the switch is set for the main track, or for which side. Red and green lights are not to be used for switch signals, unless in special cases they are to serve at the same time as danger or cautionary signals.

These regulations are complied with in the most differing ways. As a rule, the case of the signal lantern forms at the same time the signal, and is connected with the tongue of the switch, so that it turns as the latter moves. The light is enclosed in glass painted white, and the signal presents the same form by day as by night. When the switch is set for the main track, the lantern shows its narrow sides in both directions, while if the switch is set for the turnout it shows its wide sides. In order to show the direction of the turnout, there is either a black arrow in the proper direction on the white sides of the lantern, or else the side of the lantern itself is given such a form as will show the direction.

Although, however, the switch signals have lost in importance as regards train movements, they have retained their full importance as regards shifting or drilling movements. In the latter, particularly, derailments are frequently caused by cars running over a facing switch while it is being thrown and the points are not in contact with either fixed rail. In order to indicate with certainty the contact of the

tongue with the fixed rail, devices have been constructed in which a red surface or light is shown as soon as (or just before) the tongue leaves the fixed rail. The switch may therefore have three distinct positions, viz.: (1) for the main track, (2) intermediate position—danger, and (3) for the turnout.

The firm Max Jüdel & Co., in Brunswick, makes such a signal, in which the lantern is six or eight sided. When set for the main line it presents a white surface or light; in the intermediate position it shows red, and when set for the siding it shows white, with a black arrow.

H. Backofen, of Pesth, proposes a small semaphore with the following three positions of the arm: obliquely upward for the main track, horizontal for danger, obliquely downward for siding. The prolongation of the arm carries glass shades of corresponding colors.

A similar signal, that of Cumming, has been introduced in America by the Pennsylvania Steel Company, except that the arm is vertical when the switch is set for the main track. In this signal the arm takes the horizontal position, or red light is shown when the lever is unlocked preparatory to throwing. When the switch is set for the siding the proper signal appears as soon as it is locked.

Latowsky's Steam Alarm.—The shrill sound of the steam whistle is objectionable and disagreeable, particularly when a railroad runs close to an important road or street, or even upon one, as may be the case with so-called secondary roads. The regulations for secondary roads in Germany prescribe, therefore, that wherever there are unprotected highway crossings at grade, the locomotive must be provided with some other form of alarm.

For this purpose Latowsky has made a steam alarm which is as ingenious as simple. He evidently had in mind the rattling made by the cover of a pot on the fire. Steam enters a vessel through a small orifice, and escapes through a wide opening above which is covered by a rattler, upon which is a hammer. This hammer strikes upon a bell which surrounds the vessel, making 200 to 220 blows per minute, independent of the steam pressure in the boiler; indeed, it strikes more rapidly the lower the pressure. A boiler pressure of two atmospheres is sufficient to work the apparatus. In the newer alarms the steam is conducted through a receiver to the chimney after being used.

Drilling Signals.—In order to direct the signal-men in the signal

towers of large stations as to the drilling movements desired, vocal or hand signals are generally insufficient. Whistling signals, though much used, have proved too annoying to people in the neighborhood, especially near large cities or much-traveled streets, and have had to be partially given up, notwithstanding their suitability. The use of a speaking tube leading from a suitable point in the yard to the signal towers has proved practicable only for short distances. Other means have therefore been brought into use. One of these is the "drilling clock" (Rangiruhr), which has proved satisfactory, and in which communication is made with the signal-man by mechanical means. It consists of two discs, one of which is operated by the man in charge of the shifting, and is conveniently located for him, while the other is in the signal tower. Both discs are graduated and labeled to correspond with the different switching movements, and the disc in the tower also has designated upon it the position of the switches to be set for each movement. The discs are connected by a wire and rotate together, a fixed pointer indicating the desired movement. Sometimes the discs are fixed, and the pointers rotate.

Electrical means of communication have also been used in some devices. Of these, however, the electrical indicators introduced on French roads are said to have proved too fragile and unreliable.

Better results have been attained with the track indicator proposed by Hattemer in Berlin. It consists of a metal case, on the outside of which the numbers of the tracks are placed side by side. Above the row of numbers is a slot covered with glass, in which as many square white discs may appear as there are tracks to be indicated; and between the slot and the track numbers is a row of brass pull-rods projecting from the case. The complete apparatus consists of two of these boxes, electrically connected, one in the signal tower and one within reach of the station-master, or whoever has charge of the drilling. When the station-master wants the switches set for a certain track, he pulls down the corresponding rod in his instrument, whereupon both instruments show the proper square disc. The signal-man, by pulling the corresponding rod in his instrument, causes both discs to disappear.

Train Signals.—Numberless are the signals which have been devised for enabling the passengers or conductor of a train in motion to communicate with the engineer. As these are only to be used in case of emergency, they may be designated emergency signals. The

simplest and most common of these is the continuous bell-cord, one end of which is attached to the bell, whistle, or other alarm on the engine, which can thus be sounded. The bell-cord, however, is not easily reached by passengers, and its use requires a certain amount of strength. It has the advantage that it indicates the breaking apart of the train; but in such case, were the engineer to bring his portion of the train to an immediate stop, a collision with the rear portion might ensue, to prevent which great care would have to be exercised by the engineer and the train hands.

This introduction of continuous air brakes has rendered it possible to do away with the bell-cord, and to place it in the power of any passenger, in case of emergency, to stop the train at once. Since in case of breaking apart of a train, both parts are at once brought to a stop, all the requirements are here met in a most perfect manner. Some little time must elapse, however, before all passenger trains are completely equipped with air brakes, and until then some of the devices hitherto used must be retained.

Among these, the most common appears to be the electric train signal used on the French roads. The locomotive is connected electrically with every car of the train, the battery being placed in the first brakeman's box back of the engine. In the last brakeman's box of the train is a reserve battery with alarm. The alarm on the engine can be rung from each brakeman's post and from each compartment. The train hands communicate short signals with each other by means of press-buttons. For the passengers there is a box from which a button projects. If the button is pulled out, a cam revolves inside the box, the current is closed, and the alarm rings continuously. At the same time, signal arms appear on each side of the car, which hang vertically, and are made to appear by mechanism within the walls separating the compartments, thus indicating the compartment from which the alarm was given. When the alarm has been given, the passenger cannot push back the button into its original position; but when the arms are made invisible by being pushed back into the horizontal position, the cam of the instrument is revolved into a position such that the button can be pressed back.

On Austrian roads the emergency signal of Rayl is recommended for general use. At the head of the train, or at each end, is an alarm, and at each end a battery, the two connected by a circuit, but in

opposite directions. The metallic brake rods, etc., may be used as one part of the circuit. Normally no current passes, but when the two parts of the circuit are connected at any point, a current passes from each battery and the alarm is sounded. The connection is made by revolving a shaft which runs continuously over the tops of the cars, which can be done from within.

Another electric train signal is that of Griggs, used on some of the American roads. This blows a special whistle on the engine, by means of the compressed air from the train brake-pipe.

Finally, we may mention that the Pennsylvania road has introduced instead of the bell-cord a continuous rubber hose under the car body, which is supplied with compressed air at a pressure of little over one atmosphere from the compressed air reservoir. This is connected with the whistle in such a way that, as long as there is pressure in the pipe, the whistle does not sound, but when the train breaks apart or the pressure is released by opening a valve, the whistle sounds until the pressure is restored. Other signals can also be given by this apparatus.

Signals for Help.—If a train meets with an accident and is stalled on the road, it is necessary to send word to the nearest station and get assistance. Such cases are fortunately rare, so that a complete signal system has not been developed. If the stations are not far apart, the quickest and surest way will generally be to send out a messenger, particularly on roads using the block system and where trains follow each other closely. If, on the contrary, the stations are far apart, some roads have placed intermediate telegraph stations at suitably situated section-houses, which are only to be used in case of necessity, and are operated by trackmen. In some cases, also, the existing telegraph line has been arranged so that instruments can be inserted at certain points, the instruments being kept ready for use in case of necessity in the nearest section-house. To carry telegraph instruments for this purpose on trains, however, appears inadvisable, considering that in case of accident the instruments as well as the operator are exposed to danger.

The methods which have been described, however, serve more to send telegrams from intermediate points on the road than to signal. Although special means of giving signals for assistance are not generally provided, the continuous electric block signal apparatus, such as is

found throughout Germany and Austria, offers a means of giving such signals. If, as is generally the case in Austria, the bell signal circuit is operated with a closed circuit, all that is necessary is to provide the intermediate (emergency) stations with current breakers. Each time the circuit is broken, the bell strikes once at each station on the section, so that the desired signal can be given by a certain combination of strokes. For instance, the signal "locomotive wanted," is given by five strokes repeated three times. Five strokes and one stroke, repeated three times, is the call for an engine with workmen. If the key is operated by the hand, inaccuracy may lead to misunderstanding in the case of a signal which derives its meaning, not simply from the number of strokes, but also from their grouping. Many roads, therefore, for signaling of this kind, use automatic keys, operated by the hand or by clockwork, which make such errors impossible.

If the alarm circuit is operated by an induction current, it may be used also for a battery current too weak to operate the alarms, but sufficient for the signals for assistance. Making use of this principle, Siemens & Halske have added to their alarm apparatus a special device by which signals can be given at Morse printing instruments inserted in the circuit at the end stations of the sections. For this purpose an insulated brass disc with depressions along its edge is placed on the axis of the alarm. A contact spring presses on the edge, and the circuit is only closed while the spring passes over a depression. This alternate closing and breaking of the current, as the disc revolves, produces the Morse characters if the depressions on the disc are properly proportioned. The number of signals which can be given is limited by the fact that each signal requires a special disc as well as a special key for bringing the contact spring over the discs and at the same time releasing the alarm. Each disc gives also on the Morse strip, at the station, on either side, the number of the alarm from which the signal is given.

This apparatus works perfectly as long as the alarm is wound up. If it should run down and the contact spring happen to be between two depressions, the circuit would be broken.

If a signal for help is given from any point, an alarm is given at the two neighboring stations, upon which the signal-men at those stations are at once to insert the Morse instrument in the circuit, and take the message. In order that they may have time to do this, the signal key must be held in the alarm which has been released until the latter has

given 42 to 48 strokes of the bell. If the signal has been correctly received at the adjacent stations, one of the latter replies by giving the so-called "alarm signal," which consist of six strokes six times repeated, and which is, of course, produced on all alarms in the circuit. The signal is generally given from the station which has last signaled the train in question. If the alarm signal is not given shortly after the signal for resistance, the latter must be repeated till it is acknowledged. Since, however, while a train is passing a certain section, the telegraph apparatus at the two end stations is closely watched, in order to give or receive notice of the arrival of the train at the further station, the operations involved in giving, receiving, and acknowledging a signal for help generally take place very quickly, seldom requiring more than four minutes.

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TRANSMISSION OF POWER IN OPERATING CABLE RAILWAYS.

By ROBERT GILLHAM, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The subject of power and power transmission will not be considered in this paper theoretically or mathematically; but in a practical manner. It is proposed to treat of that branch of the subject which relates more particularly to cable street railways.

One cannot enter the central power station of a cable railway system without feeling impressed with the mechanical results secured. Large engines, working day and night and knowing no rest; large rotating gears, whose continued roar tells the story of mechanical work, which is in turn performed by the steel cables which pass out into the street from rapidly moving driving-drums. This activity, these moving gears and drums, the regular click of the engine valves,

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

all tell the interesting story of power generation and power transmission. To those not informed, a scene like that ordinarily presented in an operated cable railway station is bewildering and confusing in the extreme. It commands respect and admiration, and while the result of power generation is invisible, the mind cannot measure, even by comparison, the ever-varying degrees of power developed.

The engineer, at the side of the engine cylinder, with oil-stained overalls, takes a little paper card from a small instrument, the indicator, which tells, in detail and with certainty, much about this question of power. We will, in imagination, visit a few cable power stations, and learn, if possible, something about their arrangement and machinery for power transmission, etc., and, by taking a few indicator cards, try to learn something about the great forces that operate them.

Kansas City, Mo., has, it is said, one of the most complete cable railway systems in the country. Without passing on this point, it may be said that this city is most thoroughly supplied with cable traction. Kansas City is noted for its bluffs and hills, and for this reason the cable railway finds a wide field of usefulness here.

The location covered by the Kansas City Cable Railway Company's Eighth and Ninth Street lines is, no doubt, the most difficult cable railway location to which we can refer. This road was promoted and built by the writer, following the first San Francisco roads. It is considered a pioneer road, and when it was proposed to operate the main cable around right-angle curves, it was considered impracticable by many engineers, and in this case we have the first application of the main cable operating such curves.

Curves were, up to this time, operated by auxiliary cables.

There are two right-angle curves on this line, each of 55-ft. radius. Commencing at the western terminus of the line, at the Union Depot, we find an elevated waiting-room above the street, then a level piece of track for a distance of about 250 ft., then a 19% ascending grade on an elevated steel structure, which extends to the summit of the high bluff, a distance of about 1 000 ft. From the summit a 10% descending grade for a distance of 350 ft. reaches the power station.

The grades from the power station all descend to Main Street, where an ascending grade of 15% occurs for one block, then an ascending grade of 10% for one block, where a right-angle curve is located.

One block from this curve another similar curve occurs. The other grades vary from a level to 8 per cent. It will be seen that the power station is near the western terminus of the road, as well as near the steep incline.

The cable is 22 000 ft. in length, passing from the power station and running to the extreme eastern terminus of the road, then returning to the western terminus at Union Depot; thence by the south conduit to the power station. The length of this division of the road is about 2 miles, double track.

In the power station are two 24 x 48 in. Wright engines, one of which operated the road until the Washington Avenue line was added. The engine shaft has a pinion keyed to it, 6 ft. in diameter, 15-in. face, 5-in. pitch, which drives a large gear on the main-line shaft, 10 ft. in diameter, 15-in. face, 5-in. pitch.

The main-line shaft extends back of the driving drums, on which is arranged a clutch pinion 6 ft. in diameter, 10-in. face, 4-in. pitch, which drives the drum gears arranged on the driving drum shaft; these gears are 10 ft. in diameter, 10-in. face, 4-in. pitch. The intermediate pinion between the drum gear on the intermediate shaft is 5 ft. in diameter, 10-in. face, 4-in. pitch. The cable used is 1¼ ins. in diameter, weighing 2.5 lbs. per linear foot, total length 22 000 ft., making a total weight of cable 55 000 lbs. Speed of cable 7.03 miles per hour.

A series of three or four tests were made each month, in order to determine accurately the horse-power developed in performing the work of propelling the cars on the road under varying conditions of traffic and weather. The test began by taking 36 indicator cards on the first day of the test, making two cards each hour during operating hours, which was repeated several times each month, covering a period of about 10 months.

It will be seen by Table No. 2 that the mean power required to propel a grip car and one closed car with passengers, is 4½ H. P. There are no means of determining the passenger load on these trains, but the grip car without passengers weighed 4 800 lbs., and the passenger coach, 4 000 lbs.; these cars constituted a train. The mean number of trains operated during this period was 9.6 trains; the lowest number, 5.6 trains; the highest, 13.2 trains.

Many times when cards were being taken, the local position of

trains was such that a large proportion of them were descending the various grades on the line of railway, and, having contact with the cable compensation was thus secured, and very little power, if any, developed by the engine ; in other words, gravity for a brief period of time performed the work of the engine, when suddenly, the position of the cars on the street having changed, the engine seemed almost instantly to develop high power in propelling the cars.

The mean resistance of the engine and main-line shaft, as developed by these tests, was equal to 16.41 H. P. The lowest resistance noted was 12.24 H. P., and the highest 21.12 H. P. The variation of the resistance of engine and shaft was largely due to the Weston-Capen friction clutch on the main shaft, whose plates must have been slightly in contact, thus producing brake action. These clutches form a part of the pinion on the main shaft, and were used for the purpose of communicating power to the pinion and thence to the driving-drums. One set of these driving-drums usually requires 5 H. P. to operate them, without cable. The mean power developed in operating the cable without cars, machinery and engine was 37.24 H. P.

The total number of indicator cards taken during the tests was 333.

There was a maximum variation of about 5 H. P. in the power required for engine, cable and machinery. This variation was no doubt due to the condition of the road machinery, including the two right-angle curves having defective curve pulleys, poor lubrication and bad weather.

Commencing with Test No. 12, it will be seen that the power increased to a trifle over 42 H. P., an increase of about 14 per cent. This was largely due to changes in the road machinery, principally the carrying sheaves, which were 36 ft. apart, and almost doubled in weight. A valuable lesson in the transmission of power for cable railways can be learned by studying the elements that caused this increase of power.

The carrying pulleys originally used in this road had webs of light corrugated sheet steel, with rims from rolled plate steel, with a groove for the cable, the rim being riveted to the corrugated web, diameter, 22 ins.; weight, 37 lbs.; diameter of journal, $\frac{7}{8}$ in. During the period of the test, a great many of these carrying pulleys were

TABLE No. 1.

TABLE OF KANSAS CITY CABLE RAILWAY TESTS.

DATE.	No. of test.	Size of engine.	Total No. cards taken.	Duration of test, hours.	Average total horse-power.	Horse-power for engine and main shaft.	Horse-power for cable and machinery.	Horse-power for cars and passengers.	Percent. total horse-power to run engine and main shaft.	Percent. total horse-power to run cable and machinery.	Percent. total horse-power to run cars with passengers.	Greatest strain on cable.	Average strain on cable.	Average No. trains run.	No. of engine.	Average horse-power per train.	REMARKS.
Aug. 7th, 1891	1	24 x 48	36	18.5	72.12	14.09	32.39	25.64	19.54	44.91	35.55	8 350	3 840	5.6	L. H.	4.578	Fair weather.
Sept. 8th, "	2	"	30	15.0	95.13	15.78	42.05	37.29	16.59	44.21	39.20	7 027	4 203	8 8	"	4.226	Curve out of order.
" 22d, "	3	"	32	16.0	94.35	12.75	33.83	47.76	13.52	35.86	50.62	9 850	4 388	9.1	"	5.248	
Oct. 11th, "	4	"	22	10.5	92.02	16.07	35.82	40.13	17.46	38.93	43.61	5 670	4 312	9.8	"	4.093	
" 26th, "	5	"	32	16.0	82.40	18.71	35.00	28.69	22.70	42.47	34.82	7 787	4 423	9.2	"	3.119	
Nov. 10th, "	6	"	34	17.0	95.73	16.00	35.84	43.89	16.71	37.44	45.85	7 840	4 178	9.1	"	4.822	
" 25th, "	7	"	34	17.0	90.00	21.12	29.76	39.12	23.46	33.07	43 47	9 000	3 700	9.2	"	4.252	
Dec. 29th, "	8	"	30	15.0	94.78	18.35	36.68	39.75	19 36	38 70	41.94	9 100	4 038	9.5	"	4.184	Snow, track muddy.
Jan. 14th, 1892	9	"	34	17.5	94.57	16.10	36.63	41.84	17.03	38.73	44.24	7 940	4 140	9.2	"	4.547	Rain and snow.
" 29th, "	10	"	34	17.0	100.52	20.03	30.57	49.98	19.93	30.35	49.72	11 730	4 250	9.2	R. H.	5.432	Track muddy.
Mar. 4th, "	11	"	34	17 0	100.13	17.01	35.86	47.26	16.99	35.81	47.20	18 050	4 230	9.2	"	5.136	
" 5th, "	12	"	34	17.0	99.60	12.23	42.20	45.17	12.28	42.37	45.35	13 670	4 620	9.2	"	4.909	Track very muddy.
" 24th, "	13	"	34	17.0	104.53	12.23	42 20	50.10	11.70	40.37	47.93	15 000	4 890	10.0	"	5.010	
May 12th, "	14	"	34	17.0	112.00	18.64	42.21	51.15	16.64	37.69	45.67	17 473	5 900	12.0	"	4.262	
June 8th, "	15	"	34	17.0	107.73	18 64	42.21	46.88	17.30	39.18	43.52	17 340	5 120	11.8	"	3.973	Rained.
" 22d, "	16	"	34	17 0	118.80	14.91	42.70	61.19	12.55	35.94	51.51	18 980	6 270	13.2	"	4.635	
Average	....	.....	33.27	16.34	97.21	16.41	37.24	43.41	17.10	38.49	44.39	11 550	4 531	9.63	....	4.526	

removed, and in their places a pulley 22 ins. in diameter, $\frac{7}{8}$ and $1\frac{1}{8}$ in. journal, from cast iron was used, weighing 76 lbs., which resulted in increasing the power required to drive the rope.

The variation of power developed in propelling cable, cars and passengers, as shown by the table, needs no comment; varying loads, conditions and weather, all contribute to the changes shown in this column.

The percentage of total horse-power to operate the engine and main shaft, cable and machinery, cars and passengers, is shown also in Table No. 1. The mean percentage of total power developed and required to overcome resistance and operate the engine and main shaft was 17.11 per cent. The mean percentage of total power developed to operate the cable and machinery was 38 per cent.

The mean percentage of total power developed to propel cars, with passengers, was 44.4%, which leaves 0.45 of 1% unaccounted for, due probably to slight errors.

The tension on the cable was observed to vary, depending directly upon the position of trains and condition of traffic.

The minimum stress on the cable was secured when six trains were operated. The maximum stress, with this number of trains, was 8 350 lbs.; the mean stress, 3 804 lbs.

The maximum stress was observed when 13 trains were operated; with this number of trains the maximum stress was 18 980 lbs.; the mean stress, 6 270 lbs. The stress on the cable is ever changing. If all, or a large proportion, of the cars are descending grades, the stress is low; if on ascending grades, the stress approaches maximum, particularly if this condition arises during hours of maximum travel.

Several extensions were made of this system, and the new Woodland power station was built. There was also another line projected, built and operated from the power station first described, called Washington and Summit Street line, requiring a rope 23 759 ft. in length.

Table No. 3 shows the tests made on the cables operated from Woodland Station, which have, with the exception of Troost Avenue, been extended since the tests were made.

The power station and machinery is, in design, like that described above, in the first station. After numerous tests, the following was adopted as a reliable result. (Table No. 3, page 550.)

TABLE No. 2.

Test of Carrying Pulleys—Kansas City Cable Railways.

Name of Line.	Reference No.	Weight of pulley.	Diameter of pulley.	Diameter of journal.	Ratio of diameters.	Comparative ratios.	Comparative weights.	Length of cable.	Horse-power per 1 000 ft. rope at 7.3 miles per hour.	Horse-power per 1 000 ft. rope at 8 miles per hour.	Horse-power per 1 000 ft. rope at 9.7 miles per hour.
		Pounds.	Inches.	Inches.							
East Ninth Street	1	40	11¾	1¼	1 to 9.4	1.00	1.0	6 202	.....	5 084	5.413
Standard of 1888	2	30	10⅛	⅜	1 " 14.0	1.39	0.75	21 260	3.184	.....	
Independence Avenue	3	76	22	1¼	1 " 19.5	2.08	1.9	8 571	.....	2.963	3.153
Main Line (old pattern)	4	76	22	⅞	1 " 25.14	2.67	1.9	15 960	2.9		
" (steel)	5	37	22	⅞	1 " 25.14	2.67	0.9	21 000	1.454		
Troost Avenue, 1887	6	.....	.....	.....	.....	.....	.....	33 600	.....	2.906	
" 1888	7	.....	.....	.....	.....	.....	.....	33 600	.....	.....	3.129
Washington Avenue	8	19	16	1/16	1 to 13.27	1.41	0.47	23 759	.....	.....	2.834

TABLE No. 3.

TEST OF CABLES—WOODLAND AVENUE ENGINE-HOUSE—KANSAS CITY CABLE RAILWAY.

ENGINE DIAMETERS.	Horse-power for engine and machinery.	Horse-power for the Independence Avenue rope.	Horse-power for the East Ninth Street rope.	Horse-power for the Troost Avenue rope.	Total horse-power for all.	Speed of engine.	LENGTH OF ROPE.
First tests, 28 x 48 ins.....	34.16	25.4	31.53	96.75	187.84	60	Troost Avenue, 33 600 ft. Independence Avenue, 8 571 ft.
Second tests, 28 x 48 ins...	37.76	26.87	33.57	104.17	202.37	72	East Ninth Street, 6 202 feet.

NOTE.—In this test, cables all taken off the drums and each indicated as put back. Each set of drums required 5 H. P.

The driving drums in both power stations are from cast iron, and are cast solid, with grooves for ropes cast in drums, and carefully turned down. The Woodland Station has the engines arranged end to end, each engine shaft having independent balance wheels and independent pinions, which pinions engage with the same driving gear on the main shaft, one on one side and the other on the other side of the gear. As a result of this arrangement, one pinion drives downward, and the other upward. This is not a desirable arrangement, if it is proposed to work the engines together for any length of time, in operating the cables with their load. Recently it became necessary to impose the additional work of operating the main line on the Woodland Station, in addition to the three roads operated daily from this station. This additional work requires the use of both engines.

The attempt to use both engines was of short duration, as one pinion transmitted power to the main gear downward, and the other on the opposite side of the gear upward. Both pinions, as well as gear, were dry loam castings; neither the pinions nor gear had cut teeth. There were inequalities and slight variations in pitch, due to strains and swells in castings, when they were made. The pinions were not absolutely and theoretically alike, although intended to be

alike, and in the very nature of things could not be, unless they were cut.

The engines and pinions would not work well together, and the disturbance was so great, that, after the fracture of one tooth, the operation of the engines and pinions together was abandoned.

We will now consider the Cleveland City Cable Railway system of which the late Colonel W. H. Paine was constructing engineer, and the writer consulting engineer.

In designing the machinery, it was thought more desirable to connect the engines directly to the main shafts, which is nothing more than an extension of the engine shafts. The main shaft was placed between the driving drums, occupying exactly the same position that the intermediate shafts of the Kansas City cable machinery occupies, and the intermediate gear in the Cleveland case became clutch gears.

The Cleveland engines are Wright automatic engines, 38 x 60 ins., the fly-wheel with each engine weighing 115 000 lbs. Revolutions per minute, 64.

The engines, as stated, are connected with the main shaft, one at each end, the main shaft having a length of 116 ft., and a diameter of 16 ins. The pinions engaging with the drum gears are 5 ft. 1 in. in diameter, 12-in. face, with $4\frac{1}{2}$-in. pitch, which are arranged for plate friction clutches, Weston-Capen type. The gears are cast iron, dry loam castings, and are all 13 ft. 3 ins. diameter, 12-in. face, and $4\frac{1}{2}$-in. pitch. The driving drums are eight in number; the last four are not with their gears, etc., placed in position, the road to be operated by them not having been built. The last set, however, is shown on the drawing, but have not been put in; those in use vary in diameter, that constant speed of engine may be had and differing speed of ropes secured. One pair of drums is 16 ft. in diameter, one pair 12 ft., and the remaining two pairs are 14 ft. in diameter. The drums have not solid rims, but are provided with renewable and movable steel groove rings known as Walker's patent rings. Each ring, which contains a groove for the cable, is independent of the others, and this allows equalization of stress, when necessary, in the cables around the driving drums. In order to equalize this unequal stress of the cable in the use of solid drums, the rope is compelled to slip in the grooves of the drums. In using the differential rings referred to, the

rope does not slip, but the rings forming the grooves and rim of the drums perform this action, and are kept thoroughly lubricated at the inner side of the ring where contact with the shell of drum is had.

In providing specifications for driving drums, it is the practice to require the diameter of the first groove of solid drums to be slightly larger than the second and third for the reason, as was maintained, that the wear on the first groove would be much greater than on any of the others.

The examinations of a number of solid drums after five or six years of use, have shown a very great reduction in the diameter of the drums, amounting to a reduction from 1 to 1½ ins., due to slip of cable. A majority of the drums examined, however, showed that the greatest wear was in the first groove. This condition of drums naturally resulted in a great waste of power, excessive and unequal stress on the cable and its rapid wear, and early destruction of the drum rim. This, however, caused no serious trouble, as the grooves of the solid drums were turned to relatively the same diameter from time to time, to correct the trouble. The differences in the circumference of drum grooves of varying diameters are much greater than imagined, even though the difference in diameter is small.

12 ft. diameter	37.699	circumference.
11⅞ ft. "	37.306	"
Difference	0.393 ft.	

Each section of cable on drums, therefore, in order to maintain equal speeds under these conditions, must slip; if a slip occurs, in addition to the wearing effect upon the grooves of the driving drums and cable, it also acts as a brake to the rotation of the drums, and thus more power is required to drive the cable.

It must be remembered, that in the operation of all cable railways, increased adhesion of the cable to the driving drums is secured by means of a tension car with a large sheave, to which the cable passes from the driving drums, and from which sheave it passes into the street.

Attached to this car, which has a horizontal movement, is a chain

which passes to a deep pit at the remote end of the tension car track, to which is attached heavy tension weights, varying in different cable railways from 3 000 to 7 500 lbs. By the weights acting on the movable car, all slack coming into the station is taken care of, as well as the resistance on the driving drums maintained.

In this power station, crude oil is used for fuel for the generation of steam.

The writer wishes now to point out a few interesting facts relating to the test and computation of power developed in the operation of these cable railways.

TABLE No. 4.

CLEVELAND CITY RAILWAY.

NAME OF LINE.	SPEED PER HOUR.	LENGTH OF CABLE.
West Payne Avenue	12 miles	24 050 ft.
East Payne Avenue	12 "	25 300 "
West Superior Street (changed from 10 to 12 miles per hour)	12 "	24 300 "
East Superior Street	14 "	23 900 "
Water Street (auxiliary cable, driven by West Superior Street cable	4 "	7 850 "

One of the problems in designing this railway was the operation of the cable from the Post Office Park to Water Street, on West Superior Street, where electric cars, horse cars and cable cars are compelled to use the same track, and where the headway of cars, due to the common use of this section of the road, is as low at certain hours as 1½ minutes.

From Superior Street the line follows Water Street to the Union Depot. This difficulty was met by operating this section of the railway by means of an auxiliary cable 7 850 ft. in length, driven by means of auxiliary driving machinery in a vault under Superior Street, at the Post Office. The auxiliary machinery is driven by power taken from the West Superior Street main cable, which runs at a speed of 12 miles per hour, and which, in turn, by the arrangement of the auxiliary machinery, operates the auxiliary cable to the Union Depot at a speed of 4 miles per hour.

TABLE No. 5.

CLEVELAND CITY CABLE RAILWAY.

(Table Illustrating Brake Action of Friction Clutches.)

TEST.	LOAD.	Indicated horse-power.	Length of cables in ft.	REMARKS.
1.....	Engine and line shaft only.	143.65		It will be noticed that the sum of the H. P. of the individual tests of each cable (without cars) is 802.03 H. P., which sum, if correct, would equal the power required to drive all the cables empty. Test No. 6 gives the actual power required to operate all the cables with 30 trains and their load as 509.56 H. P., which is correct, as the clutches, when all thrown in, could not exert brake action. The difference between these amounts is brake action 292.47 H. P. The total brake action in tests for cables only exceeds this amount by the power required for cars.
2.....	Engine, line shaft and East Superior Street cable only.	173.51	23 900	
3.....	Engine, line shaft and West Superior Street cable only (auxiliary cable).....	141.50	24 300	
4.....	Engine, line shaft and West Payne Avenue cable only.	158.93	24 050	
5.....	Engine, line shaft and East Payne Avenue cable only.	184.44	25 300	
	Total.....	802.03		
6.....	All cables in operation and 30 trains or 64 cars in operation.....	509.56		
	Difference.....	292.47		

Total power computed from first series of cards, which were taken when all the cables were in operation, including auxiliary and including also engine and shaft resistance, was.....	487.14	H. P.
Total power determined by individual test of cables, by first taking cards for all cables, and then throwing out one cable and indicating the others, and thus testing each cable, in the same manner, without engine and shaft friction, gave as indicated in table.....	354.42	"
Engine and shaft friction, as shown by cards for same.	122.37	"
Total	476.79	"
Power unaccounted for.....	10.35	"

It will be observed that the high-speed cables require much more power per linear foot than the other cables when considered independent of curves.

The cables are all 1¼ ins. in diameter and weigh 2.6 lbs. per linear foot.

The tests illustrating brake action are given for two purposes, one to illustrate the fact that all tests made of cable plants and power developed cannot be relied upon, and also for the purpose of pointing out the elements of error in these tests.

TABLE No. 6.

Cleveland City Cable Railway (Cleveland, Ohio).

Cable No.	Name of Cable.	Length of cables in feet.	Speed of cables in miles per hour.	Horse-power required for cables.	Horse-power required per linear foot of cable.	Remarks.
1.....	East Superior Street.....	23 900	14	78.43	0.00328	Practically no curves on this cable.
2.....	West Superior Street.....	21 300	12	61.25	0.00252	Practically no curves on this cable.
3.....	East Payne Avenue.....	25 300	12	144.13	0.00569	Four right-angle double-track curves.
4.....	West Payne Avenue	24 050	12	56.11	0.00233	No curves on this cable.
5.....	Water Street Auxiliary	7 850	4	14.50	0.00184	One double right-angle curve.

Computations of cards taken for the purpose gave for engine and shaft friction, 122.37 H. P. Total, as given above, 476.79 H. P.

Shortly after the indicator cards were examined, and the computation of power made, the company was notified that one or more of the friction clutches were out of adjustment. Before the difficulty was corrected, on many occasions it was noticed that the West Superior cable clutch, if thrown out temporarily for the purpose of making necessary examination of the cable, would almost instantly become heated, and on several occasions it became so hot that a stream of water from a small hose had to be used to cool it. An examination of the clutch and its movements developed the fact that the horizontal movement of the plates constituting the clutch was not sufficient, and generally left the plates slightly in contact with the fixed plates that rotated with the shaft, when the lever was in a position that should maintain absolute separation of the friction plates. The only means of relief was to take the cable off the driving drums when it needed repairs, throw the clutch in, and operate the empty drums with the rest of the machinery, until the cable had been repaired, when the drums were for a few minutes stopped and the cable replaced on them and again started. These defects were corrected and the clutches properly adjusted.

On another occasion, the tests made to determine the power developed during hours of maximum travel, when compared with the power required to operate empty cables on the same day, developed the fact that the clutches were all more or less acting as brakes on the empty cables tested, the others being idle. This could have no effect upon the work of the engine if all the cables were in operation, but if any one of the cables had been stopped for any purpose, brake action on the rest would immediately take place.

It was discovered that the engineer had not properly lubricated the friction plates of the clutches, which had become gummed up with old oil and which caused the plates of the clutch to adhere to each other. It was found that cards in Test No. 1 (in Table No. 5) gave a mean resistance of 143.65 H. P., and cards in Test No. 3 (in the same table) gave 141.50 H. P. This is more remarkable when it is understood that to the work of the engine as shown on cards in Test No. 1, which are supposed to indicate only the power developed in operating engine and main shaft, all the driving drums and cables remaining idle, there is added the West Superior Street cable, 24 300 ft. in length, driven at 12 miles per hour, and the auxiliary machinery at the Post Office, including its cable, 7 850 ft. in length.

The fact was developed in subsequent tests, that the power required to operate the West Superior Street cable auxiliary machinery and its rope was 75 H. P.

The power test of the Cleveland Cable Railway, illustrated in Table No. 6, is correct, and was made after clutches had been properly adjusted.

It is needless to say that, in many tests, this brake action of clutches has not been noted, and the world is informed that the resistance of cable machinery is too high, and no considerable economy can be secured in the operation of cable railways.

Thus it is errors creep into census bulletins, lectures and papers on the subject of cable traction.

The Denver City Cable Railway system, is, perhaps, the largest single cable plant in the country, that is, there are more miles of cable railway operated from its power station than from any other single power station in the world, which affords a very excellent opportunity of studying the question of power transmission in its relation to cable railways. The writer, in designing this system, concluded to use cotton rope or belt transmission from the engine to the main shaft, and thus do away with the necessity of using cast-iron pinions on the engine shaft, and a large extra gear on the main shaft. In order to operate the entire system from a central power station, it became necessary to secure a certain piece of property, the only remaining available piece being too small in area to attempt the construction of any but a very compact plant. Therefore, rope and belt transmission was not considered in the final design for this machinery.

From the power station there are six cables operated, having the following lengths and speeds:

TABLE No. 7.

DENVER CITY CABLE RAILWAY.

No.	NAME.	SPEED PER HOUR.	DIAMETER.	WEIGHT PER FOOT.	LENGTH.
1.....	Larrimer Street.....	10 miles.	1¼ in.	2.6	23 100 feet.
2.....	Sloan's Lake.....	"	"	"	31 250 "
3.....	Seventeenth Avenue.	"	"	"	31 347 "
4.....	Welton Street.....	"	"	"	36 850 "
5.....	West Denver.	"	"	"	28 000 "
6.....	North Denver.....	"	"	"	25 270 "
			Total lin. ft. over 33 miles.		175 817 "

The engines are automatic cut-off engines, two in number; cylinder, 36 ins. in diameter; stroke, 60 ins.; engine shaft, 20 ins. in diameter; fly-wheel, 20 ft. in diameter, weighing 125 000 lbs. Revolutions per minute, 56.

On the engine shaft, between the engines, are arranged two pinions bolted together side by side, staggered so that the teeth of one alternate with the teeth of the other. The diameter of these pinions is 9 ft. 3 in., each 20-in. face, making a total face of 40 ins.; the pitch, $7\frac{1}{2}$ ins.; total weight, 45 000 lbs.

The gears on the main shaft were 12 ft. 10 in. in diameter, 20-in. face, each staggered like the pinions, making a total face of 40 ins.; pitch, $7\frac{1}{2}$ ins.; total weight, 70 000 lbs.

The large gear was allowed to run in oil at the lower side in the gear pit. The peripheral speed of these large gears was 2 257 ft. per minute.

The pinions on the main shaft engaging with drum gears are all clutch gears, and are 12-in. face, $64\frac{1}{2}$ ins. diameter. The pinions on the intermediate shaft are 5 ft. in diameter, 12-in. face, and $4\frac{1}{2}$-in. pitch. All drum gears are 10 ft. in diameter, 12-in. face, and $4\frac{1}{2}$-in. pitch. The driving drums are 12 ft. in diameter and have six grooves. All pinions and gears are from cast iron, and are dry loam castings, and are not cut gears.

For two years the large engine gears worked very satisfactorily indeed, although, with the heavy work performed, they occasioned considerable noise and jar. Finally, one night, when the engines were about to cease operations, two teeth in one of the large gears broke, but the other gear of 20-in. face was still in perfect condition. The mean horse-power developed during the day was about 800 H. P. The writer advised the operation of the road with the single gear of 20-in. face, as this had ample capacity to transmit the maximum power required for the operation of the cable railway.

This gear ran for several months, when the pinion developed a fracture. New gears were substituted, as well as new pinions; these were made from cast iron, and were not cut gears.

A change was made in the designs and arrangement of these gears and pinions. The pinion is 111.9 ins. diameter, 32-in. face, 8.57-in. pitch. The gear is 152.8 ins. diameter, 32-in. face, 8.57-in. pitch, and were single pinion and gear, and cast in halves, instead of double gears as before.

These operated successfully for a period of seven or eight months, when again during the night, as is reported, the engine frame was fractured, and the rim of the large gear cracked. These injuries were repaired and the road operated as befor

Cast-steel cut gears will soon be substituted for the cast-iron pinions and gears now in use. These will have the same dimensions as the first gears and pinions described; same weight, same diameter, but a pitch of 6 ins. instead of 7½ ins.

There is no reliable explanation given by the engineers in charge that throws much light on these accidents. One thing can be relied upon, that the power developed in operating the cars and cables is not sufficient to strain the pinions or gears, or cause the fractures referred to. In the operation of the road, no unusual strains occur, imposing sudden destructive shocks on engine and gears. A sudden and irresistible strain must have occurred to occasion these fractures. The cause was not fully determined, but the conclusion was that they might have been occasioned by the following causes:

First.—By water in the engine cylinder.

Second.—By the high speed of gear and irregular gear teeth.

Third.—By inadjustment of the main shaft.

Fourth.—By loose bolts holding the gears together.

Fifth.—By strain in castings, due to forcing halves together.

It was discovered that, during the night of the accident, considerable water had accumulated in the cylinder during the two hours following the close of the night. If this statement is true, then the cause of these accidents is due, no doubt, to the accumulation of water in the engine cylinders; the gear speed is high, but on other work no trouble has arisen on account of high gear speed, and the fact that for two years no trouble arose tends to indicate that the fracture of gears and pinions was due to some other cause.

The road machinery is well maintained and offers no more resistance to operation of cable than is found in the best-designed cable railways. The gauge of track is 3 ft. and 6 ins. There are seven right-angle curves in the system, and five curves covering 45° of a circle. Two large steel viaducts form a part of the system. In the Denver machinery, as in other plants, there were indications that more power was being developed than was really necessary for the operation of cable and cars. The grooves in the driving drums were found to be

considerably worn, having irregular depths. The writer had a series of tests made, which were placed in the care of his principal assistant, Mr. Towson. After considerable experimenting and careful testing, it was assumed that on this road the power required to operate various special parts of the cable railway was as follows :

One 90°, 55 ft. radius, double-track curve, 20.64 H. P.

One 45°, 55 ft. radius, double-track curve, 10.34 H. P.

Elevating and depression and let-go sheaves, 0.503 H. P.

Each linear foot of cable, straight track, for cable only (not including engine and machinery resistance), .001612 H. P.

Applying these factors in the computation of power required for the cables in question, and comparing the results with the results secured by actual test at a later date, will be interesting.

TABLE No. 8.

DENVER CABLE RAILWAY TESTS.

Cable No.	Name of line.	Length of rope.	Theoretical power.	Actual power.	Power unaccounted for.	Remarks.
		Feet.	H. P.	H. P.	H. P.	
1.....	Larrimer Street.....	23 100	60.352	126.297	65.945	
2.....	Sloan's Lake.....	31 250	77.514	100.54	23.023	
3.....	Seventeenth Street.....	11 850	26.647	27.827	1.18	
4.....	Welton Street.....	36 850	133.001	208.738	75.727	
5.....	Seventeenth Avenue...	25 297	73 187	74.195	1.008	
6.....	North Denver.....	25 271	52.639	53.695	1.056	
7.....	West Denver.....	28 000	.....	.....	.....	Not in operation.
	Totals.....	.....	423.270	591.192	167.942	

The great difference between what is given as the theoretical test (deductions from experiments), and the power actually developed in the tables, is an evidence of either error or defective machinery. It was due largely to the latter. We were aware, as stated, of the fact that several of the driving drums, which were solid rims, had worn considerably, and needed re-turning in order to secure uniform diameters. The road machinery was all thoroughly readjusted, and the driving drums were accurately turned, securing a uniform diameter, and the inaccuracies corrected. On account of the absence of the engineer, cards were not taken immediately after the drums were turned.

Mr. Towson, however, was in Denver when the drums operating Cable No. 4 (Welton Street Cable) were re-turned and adjusted, and

secured cards from the engine immediately afterwards, which showed an actual saving of 80 H. P. over the power required to drive this cable before the drums were turned. It will be observed that this amount is a little in excess of the amount indicated as the power unaccounted for opposite Cable No. 4, the one in question. After all the tests were carefully examined and compared, the result showed that the total power saved by re-turning these drums and adjusting the road machinery aggregated 200 H. P.

The actual test referred to in Table No. 8 was made as follows:

The total power required to drive six cables empty (without cars) was determined, one of the cables was then stopped, and the power for the remaining five in operation determined.

The difference between the power required for the six cables and that required for the five cables is the power required for the cable in question. This method of stopping one cable and indicating all the others, so that at each indication five cables were in operation, was followed throughout the test, thus securing a result that does not include the loss in transmission through the engine, gears, and main shaft. The clutches were not all in good adjustment when these tests were made, and when all the cables were stopped and cards taken for the engine and shaft resistance, the brake action due to the clutches was such as to make the cards of little value. In making the test below, only one clutch was thrown out during each indication, which was watched and adjusted so that no great error could enter the computation.

The Welton Street cable has three right-angle double-track curves and one 45° curve, and had a cable in use that was made up with large outside wires, making it ridged. This character of cable was adopted for the purpose of securing longer life, which was not realized, but which required a little more power than one with smaller wires on the outside surface of cable.

A good example of power required in operating a cable railway may be found on the Missouri Railway's Olive Street line, St. Louis, Mo. It is double track, 4.75 miles in length. There are two right-angle curves and two curves of 300 ft. radius, 84 ft. long; also one 1 000 ft. radius 30 ft. long, and one 300 ft. radius and 80 ft. long, and two 600 ft. radius and 75 ft. long. The curves outside the right angle curves are not very objectionable.

TABLE No. 9.

1892. (March.) DENVER CABLE RAILWAY TESTS.

Cable No.	Name of line.	Speed of cables per hour.	Length of cables.	Horse-power, first test for cables only.	Horse-power, second test for cables only.	Mean power.	Mean horse-power per linear foot of cable, no cars in operation.	Trains of two cars operated during the following test.	Test of power for cable and trains.	REMARKS.
1.....	Larrimer St.....	10	23 100 ft.	125.95	126.645	126.297	.005467	15	Total power developed, all cables, including West Denver, and loads (with cars) July 26th, 1892, 1 146 H. P.; July 27th, 1 115 H. P.; July 28th, 1 155 H. P.; July 29th, 1 118 H. P.; July 30th, 1 236 H. P; July 31st, 1 111 H. P.	Cables connected by brackets are on the same route, and the cars are operated on both; that is, the number of trains operated means number on both cables thus connected. *Not in operation and not fully completed.
2.....	Sloan's Lake	10	31 250 "	95.045	106.035	100.540	.003217			
3.....	Seventeenth St...	10	11 850 "	30.925	24.730	27.827	.002348	6		
4.....	Welton St.	10	36 850 "	211.835	205 640	208.738	.005664	12		
5.....	Seventeenth Ave..	10	25 297 "	77.860	70.530	74.195	.002932	10		
6.....	North Denver....	10	27 270 "	51.535	55.655	53.595	.002120			
7.....	West Denver.....	10	28 000 "	.....	.....	.....	.....*	8		
Totals		.....	183 617 ft.	593.150	589.235	591.192	.003624	51 trains.	1 147 H. P.	

The above cables are operated from a single power station.

There are two cables, one downtown 23 800 ft. long, and one uptown 25 248 ft. long, giving a total length of 49 048 linear feet, weighing 2.6 lbs. per linear foot. Power required to operate cables, 49 048 ft., and engine only, is 136 H. P., or 0.0028 per linear foot of cable.

The late Colonel W. H. Paine, M. Am. Soc. C. E., and the writer, made tests of the Tenth Avenue Cable Railway, New York City, which was constructed by the late D. J. Miller, C. E., and Colonel Paine, who also constructed the East River or Brooklyn Bridge cable in the same city.

The engines are automatic engines, cylinders 28 ins. diameter by 48-in. stroke, 62 revolutions per minute. The engines and machinery are arranged something like the Denver plant. The resistance of engine and main-shaft resistance was equal to 58.95 H. P. The resistance of engine, main shaft and one set of drums, with their shafts and gears, was equal to 71.74 H. P. The resistance of engine, shafting, one set of drums, gears and cable was equal to 140.29 H. P. Power required per linear foot of cable, 8 miles per hour, not including machinery resistance, 0.0015 H. P.

A paper relating to the subject of cable railways would not be complete without a reference to the Chicago City Railway, for the reason that this road was one of the pioneer roads of the country, and has demonstrated that cable railways can meet all the conditions imposed by reason of climatic changes.

The writer is indebted to Mr. Robert J. Hill, Chief Engineer of this railway, for the information presented relating to it.

There are two power stations in this system, one at Fifty-fifth Street and Cottage Grove Avenue, and the other at Twenty-first and State Streets. The former plant consists of two Wheelock automatic engines, 36 ins. in diameter and 72-in. stroke, and one always in reserve in case of emergency.

The engine operates four cables :

		Length.
No. 10.	Cable Fifty-fifth to Thirty-ninth Street and return	22 572 ft.
No. 11.	Cable Fifty-fifth to Seventy-first Street and return	22 472 "
No. 12.	Cable Fifty-fifth Street to Lake Avenue and return	10 868 "
No. 13.	Cable Hyde Park loop	3 786 "
	Total length of cable	59 700 "

Revolutions of engine, 52 per minute.

The line shaft gears have 35 teeth.

The drum shaft gears have 63 teeth.

The drum shaft revolves at the rate of 28.9 rotations per minute.

The driving drums have a diameter of 13 ft. and 4 ins.

The cables are driven at a speed of 13.76 miles per hour. The total power required to operate all the cables and the machinery without cars is 382 H. P., or 0.0064 H. P. per linear foot. The maximum tension on the cables during operating hours, when travel was at the maximum, equaled 10 420 lbs., or a pull of 0.175 lb. per linear foot of cable. In order to determine the actual work performed and the load on the cables when the cars were in operation, a series of cards were taken from the engines.

From an examination of time tables and trip sheets of conductors, the load on cables can be approximated. The following table gives the result of such tests, based on the indicator cards selected.

Mean powers (maximum), less power to operate empty cables	257 H. P.
Mean load on cables	152.7 tons.
Mean net power per ton of load on cables (maximum)	1.68 H. P.
Mean power of maximum cards	339 "
Mean power of all cards, less power to drive empty cables	138.5 "
Mean power per ton of load, less power to drive empty cables	0.91 "
Mean power (maximum cards) per ton of load on cable	3.77 "
Variation in horse-power per ton of load on cables	1.55 "

Similar tests were made at the Twenty-first Street power station. Engines two in number, cylinder 30 ins. in diameter and 60-in. stroke; same type of engine as is used in Fifty-fifth Street station.

	Length.
Cable No. 1. Power Station to Madison Street and return	20 302 ft.
Cable No. 3. Power Station to Wabash Avenue and Twenty-second Street and return	23 620 "
Cable No. 5. Auxiliary for Cable No. 1, Madison Street	4 600 "
Cable No. 6. Auxiliary for Cable No. 3	4 700 "
Total length of cables	53 222 lin. ft.

TABLE No. 10.

1890. CHICAGO CITY RAILWAY TESTS—FIFTY-FIFTH STREET POWER STATION.

TIME.	Maximum horse power.	Minimum horse-power.	Differential horse-power.	Trains.	Cars.	Passengers.	Tons, Load.	Horse-power per ton. Variation.	Horse-power per ton of load (maximum) less horse-power to drive empty cables.	REMARKS.
5.30 A. M.....	319	319	.....	.....	.....	.....	.....	.....	.....	Empty cables.
6.20 "	506	319	187	13	15	600	124	1.51	4.08	
7.45 "	602	372	230	18	23	720	167	1.38	3.60	
7.55 "	620	326	294	18	23	720	167	1.76	3.71	

Average horse-power, 576. (Maximum cards.)

One train is composed of one grip car and one coach; the cars in the table refer to extra cars in train.

These engines make 55 revolutions per minute. Gear on main shaft has 34 teeth ; spur gear line shaft has 47 teeth ; pinion line shaft has 27 teeth ; spur gear on drum shaft, 53 teeth. Line shaft makes 39.8 revolutions per minute. Drum shafts make 20.27 revolutions per minute. Diameter of driving drums, bottom of grooves, 13 ft. 4 ins. Speed of cables, 9.65 miles per hour. Power required to operate empty cables and machinery, 294 H. P. Tension on cables, 11 420 lbs., or a pull of 0.127 lbs. per linear foot of cable. Power required per linear foot of cable to drive them at normal speed, including machinery, 0.0055 H. P. per linear foot of cable.

Tests were made to determine the power developed during the hours of maximum travel during the morning, with the view of making comparisons with the other tests at Fifty-fifth Street station.

Mean power of maximum cards	642.4 H. P.
Mean of maximum powers, less power to drive empty cables	384.4 H. P.
Mean load on cables	813 tons.
Mean of maximum powers per ton of load	.428 H. P.
Mean power of minimum cards	483. "
Mean power per ton of load, less power to drive empty cables	0.330 "
Mean power during tests, less power to drive empty cables	268.74 "
Mean of maximum powers per ton of load on cables	.792 "
Variation of power per ton of load on cable	.196 "

Tests were made to determine the power required to operate the cables at varying speeds.

At Fifty-fifth Street and Cottage Grove Avenue a speed of 9.65 miles per hour was tested, being the same speed as Cables Nos. 1, 2 and 3, at the Twenty-first Street power station. After the cars had been taken off the various lines for the night, it was found that in order to drive the empty cables at 13.76 miles per hour, 300.6 H. P. was developed, while the power required to drive them at 9.65 miles per hour, only 184 H. P. was developed.

The first test at Fifty-fifth Street developed the fact that the pull per foot of cables, including engine and machinery resistance, was .175 lb., and that made at Twenty-first Street station was .215 lb. per linear foot of cable. The last test at Fifty-fifth Street station demon-

TABLE No. 11,

CHICAGO CITY RAILWAY TESTS.—(Twenty-first Street Power Station.)

TIME	Maximum horse-power, one engine.	Minimum horse-power, one engine.	Four engines, maximum horse-power.	Four engines, minimum horse-power.	Difference.	Trains.	Cars.	Passengers.	Tons.	Horse-power per ton. Variation.	Horse-power per ton of load. Maximum.	REMARKS.
4.50 A. M....	144.35	.....	294	.....	.....	.....	.....	.....	.....	.....	.....	Cables empty.
7.06 A. M....	142.8	99.7	582	406	176	55	87	3 754	735	.139	.792	
7.16 A. M....	156.3	122.0	636.4	497	139.4	60	95	3 725	780	.179	.816	
7.46 A. M....	174	134.	709	546	163	70	120	4 050	924	.176	.767	

Mean horse-power, 642.4 (maximum cards).

A train is composed of one grip car and one coach. Cars in table refer to extra cars attached to trains.

This test was made with four engines in operation, which explains the references to engines in table.

strated that the pull equaled .137 lb. per linear foot of cable, at a speed of 13.76 miles per hour, and .119 lb. at a speed of 9.65 miles per hour.

This difference, Mr. Hill says, may be accounted for as follows:

"The first test was made when starting the cables in the morning, before any of the bearings were thoroughly warmed and lubricated. The last tests were made at night, after operating hours, and immediately after the cars had been taken off the street. Thus the midnight test offered the most favorable conditions."

The difference in the tests is .038 lb. per linear foot of cable, which Mr. Hill thinks is not excessive when all the conditions are considered. The greatest resistance per linear foot of cable was found at the Twenty-first Street station, in starting in the morning, which amounted to .215 lb. per foot, due, no doubt, to the down-town loops and the circuitous route of the Wabash Avenue cable. The difference between the resistance per linear foot of cable between the Fifty-fifth Street station and the Twenty-first Street station was found to be .04 per cent. The most satisfactory tests were made at the Fifty-fifth Street power station. Here the same cable was operated at varying speeds, and the tests made when the conditions remained unchanged. The ratio of the speeds were 9.65 to 13.76 miles per hour, equal to 1.43; the ratio of the pull per lineal foot is .119 lb., equal to 1.14.

In a letter relating to these tests Mr. Hill says:

"If the pull on the cable was constant, then the horse-power required to pull the cable would be in direct proportion to the speed of the cable, hence 9.65 : 13.76 :: 184 : 262 H. P.; but it was found that it required 300.5 H. P. to propel the cable at a speed of 13.76 miles per hour, and the difference $38.5 \div 262 = 14.7\%$ more power than that which might result from an increase in speed, which must be due to increased friction, etc.

"The cable being increased 43% in speed, calls for a corresponding increase of 63% in horse-power to drive it, from which it can be seen that for each increase of 1% in speed, there should be an increase of 1.47% in horse-power."

The question of engine and machine resistance in transmitting power is a subject that does not receive the attention it demands. Engineers too often underestimate the power lost in its initial transmission, due to engine and machinery resistance. Mr. Alfred Saxon, in a paper read before the Association of Engineers, Manchester, Eng.,

related the results he secured, after making careful tests and experiments of engine and machine friction in numerous cotton mills. He found that the friction under load was greater than ordinarily estimated. Interesting comparisons were made, among which were the following: ten tests of spur-gearing machines developed the fact that the friction under load averaged 25.964% of the indicated horse-power. Eight examples of rope transmission or rope-driving engines showed that under load the average friction was 29.6% of the indicated horse-power.

Belt-driving engines under load developed a resistance of 27.6% of the indicated horse-power. Direct coupled engines showed a resistance of 23.835% of the indicated horse-power.

Mr. Saxon, during his lecture, said: "Spur-gearing engines give best results when not complicated with rope drive. Rope driving engines show the best results at high rope speeds, and that direct driving from main drum is very desirable. Belt-driving engines for developing large powers are only equal to the average rope-driving engine, with fewer advantages in other respects; and finally that the direct acting type of engines is likely to be very efficient."

Comparisons are valuable in considering the question of power transmission as applied to cable railways, for the reason that many engineers favor rope driving, and can see no special advantage in gear transmission, while others favor machinery driven by belt.

In the Kansas City tests, it was found that the average friction of engine shaft and main shafting gears, and not including driving drums, gears and pinions, based on something over 300 indicator cards, averaged 17.11% of the total horse-power developed.

The Cleveland City Cable Railway engines and machinery developed a resistance or friction of 25% of power developed.

Rope and belt driven machinery has the advantage over gearing in that noise is very materially reduced.

We find that the power required per linear foot of cable 1¼ in. in diameter, weighing from 2.5 to 2.6 lbs. per linear foot, operated at the speed given, is as follows:

TABLE No. 12.

Kansas City Cable Railway.

Location.	Length of cable tested.	Speed of cables Miles per hour.	Horse-power per linear foot of cable.	Remarks.
	Feet			
Troost Avenue.....	33 600	9.7	.0031	Cast carrying pulleys, 12 ins. diameter, $\frac{3}{4}$-in. journal.
Washington Street.....	23 759	8.0	.0029	Cast carrying pulley, 16 in. diameter, $1\frac{1}{4}$-in. journal, weight 19 lbs., 32 ft. apart.
Main Line.....	22 000	7.3	.0017	Corrugated steel pulley, 22 ins. diameter, weight 37 lbs., 32 ft. apart.
Main Line.....	22 000	7.3	.0029	Cast-iron pulley, 22 ins. diameter, weight 76 lbs., $\frac{3}{4}$-in. journal.
Independence Avenue..	8 571	8.0	.00296	Cast-iron pulley, 22 ins. diameter, weight 76 lbs., $\frac{3}{4}$-in. journal.
East Ninth Street.....	6 202	8.0	.00508	Curve was probably in bad adjustment.

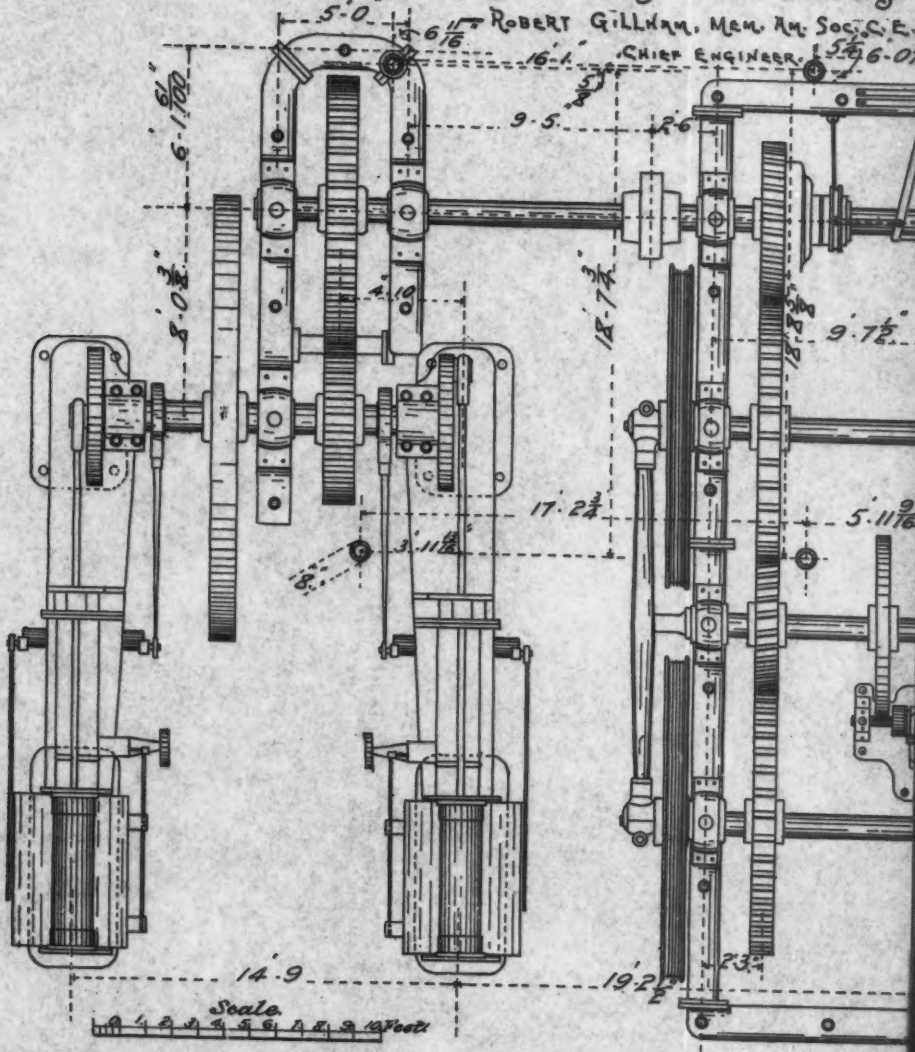
(Not including engine friction.)

TABLE No. 13.

Cleveland City Cable Railway.

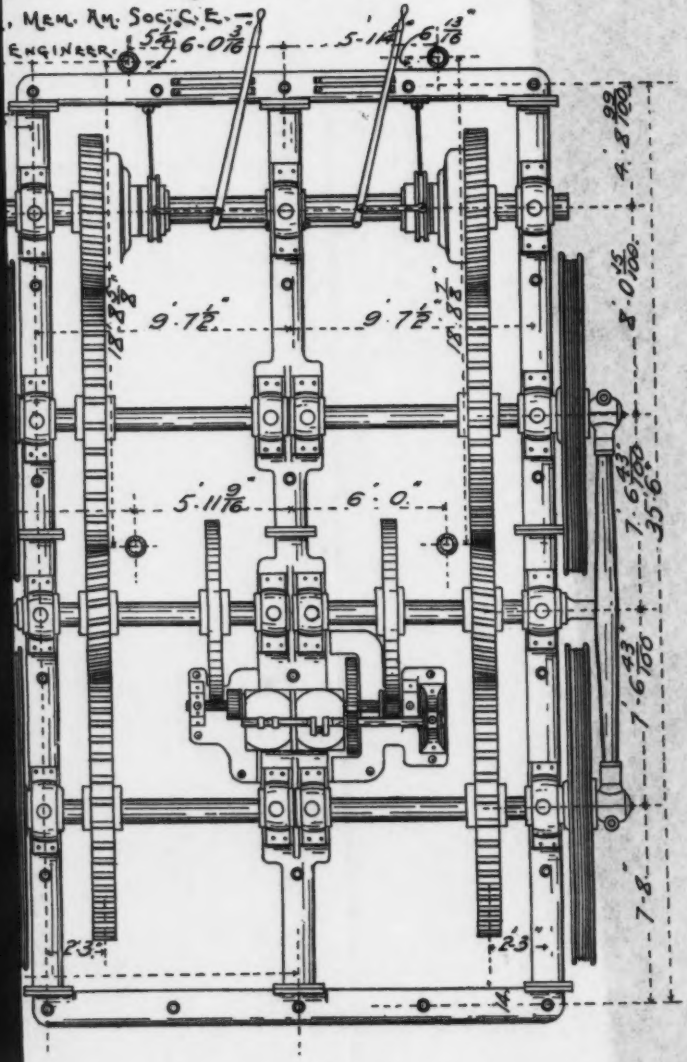
Location.	Length of cables tested.	Speed of cables. Miles per hour.	Horse-power per linear foot of cable.	Remarks.
	Feet.			
East Superior Street....	23 900	14	0.00328	Practically no curves on this cable.
West Superior Street...	24 300	12	0.00252	Practically no curves on this cable.
East Payne Avenue.....	25 300	12	0.00569	Four right-angle double-track curves.
West Payne Avenue....	24 050	12	0.00233	No curves in this cable.
Water Street Auxiliary..	7 850	4	0.00184	One double-track right-angle curve

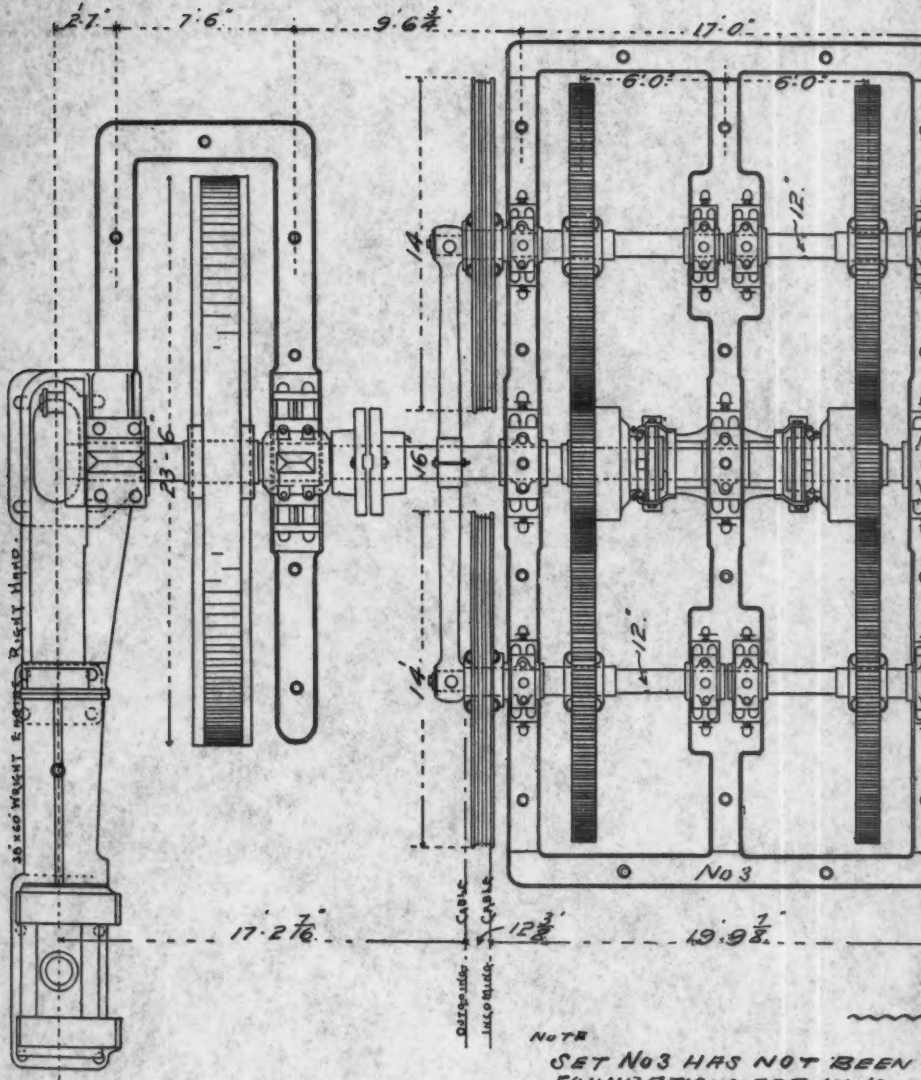
(Not including engine friction.)


Plan of Kansas City Cable Railway
ROBERT GILLHAM, MEM. AM. SOC. C.E.
CHIEF ENGINEER.
5'-0"
6 1/16"
16'-1"
9'-5"
12'-6"
6'-1 61/100"
8'-0 3/4"
4'-10"
18'-7 3/4"
9'-7 1/2"
17'-2 3/4"
5'-11 9/16"
3'-11 1/2"
14'-9"
19'-2 1/2"
23"
Scale.
0 1 2 3 4 5 6 7 8 9 10 Feet

Cable Railway Machinery

, MEM. AM. SOC. C. E.,
ENGINEER.




2'1"
7'6"
9'6¾"
17'0"
6'0"
6'0"
12"
14"
23'6"
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14"
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No 3
17'2 7/16"
Cable
Cable
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Rocky Hand.
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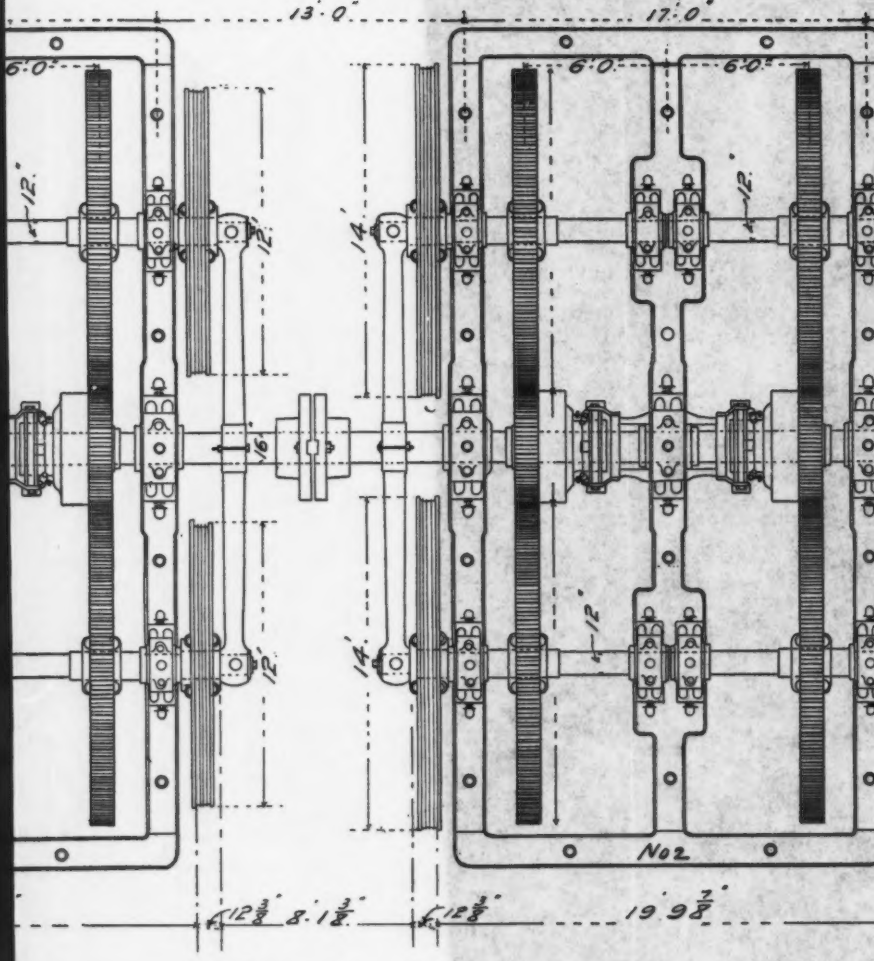

Plan of Cleveland Cable Railwa

W. H. Paine and Robert Gillham, Mem'bs Am. Soc. Engineers

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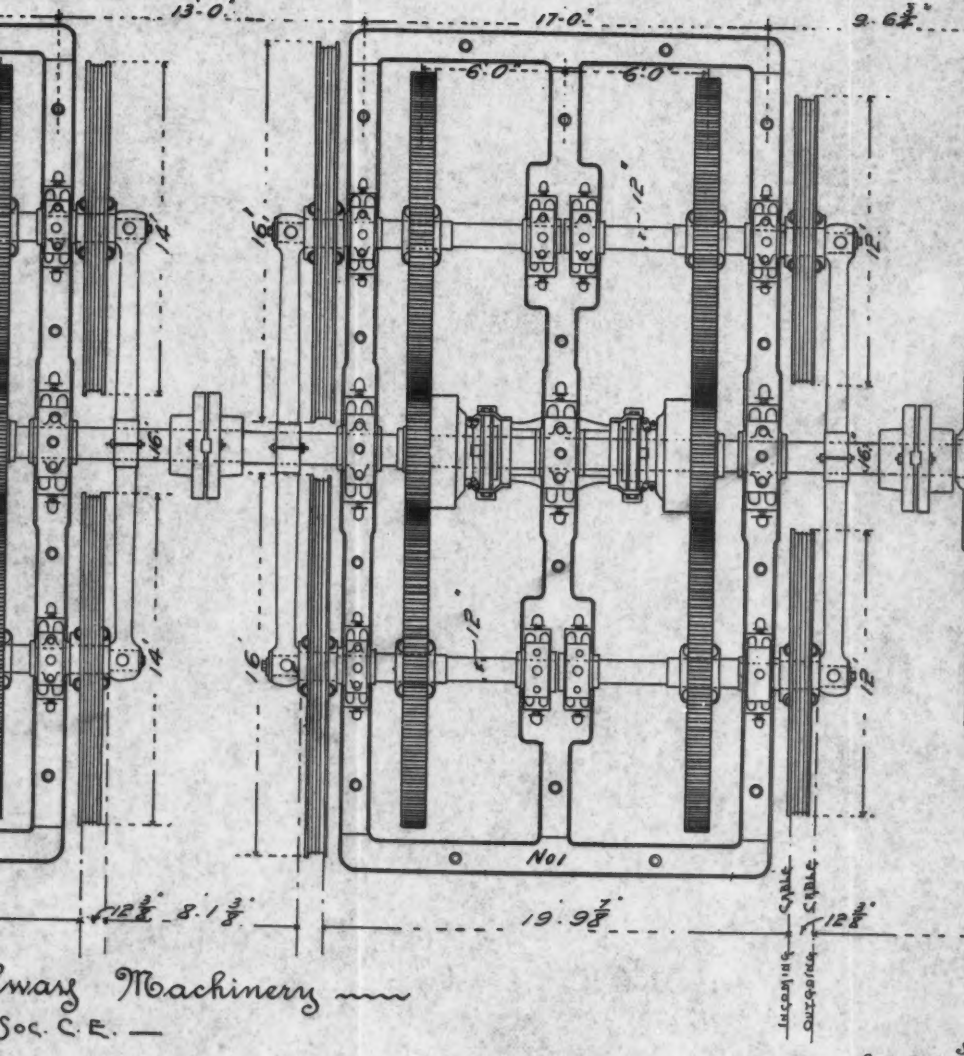
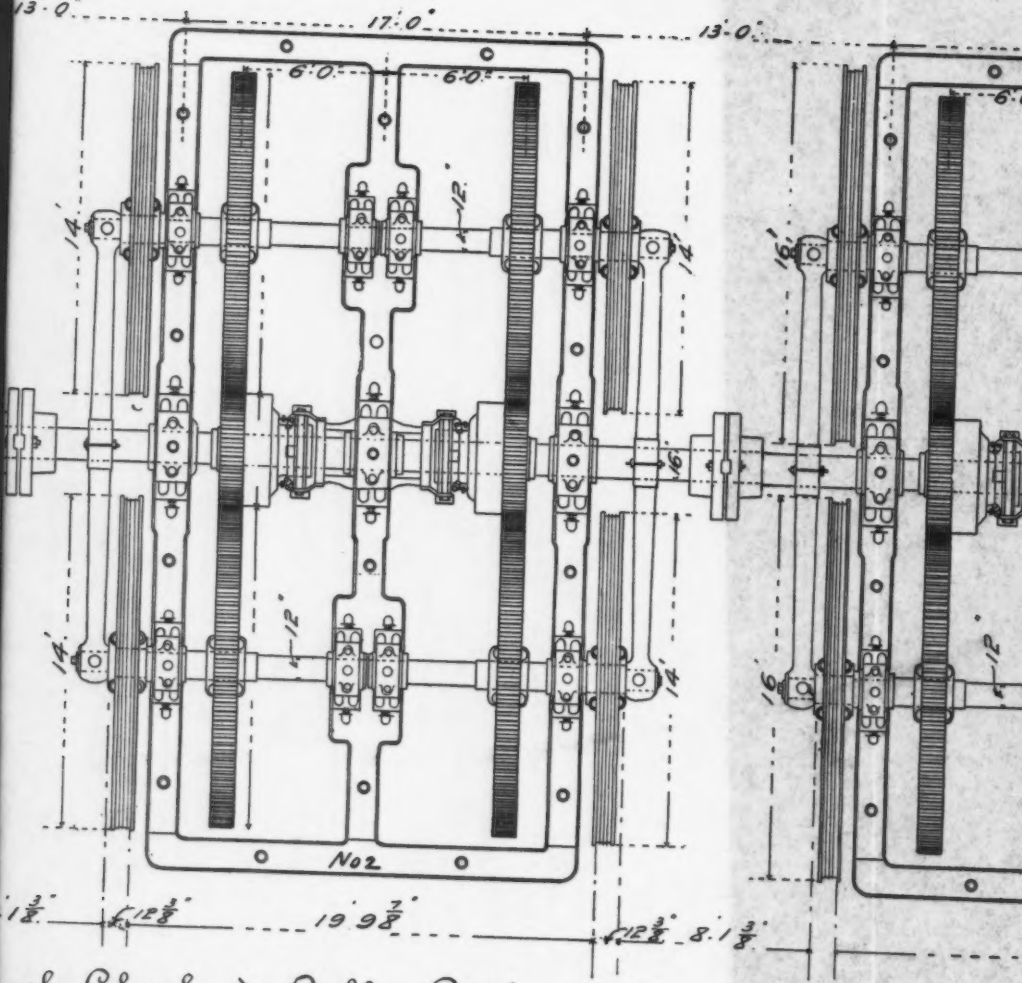


Machinery

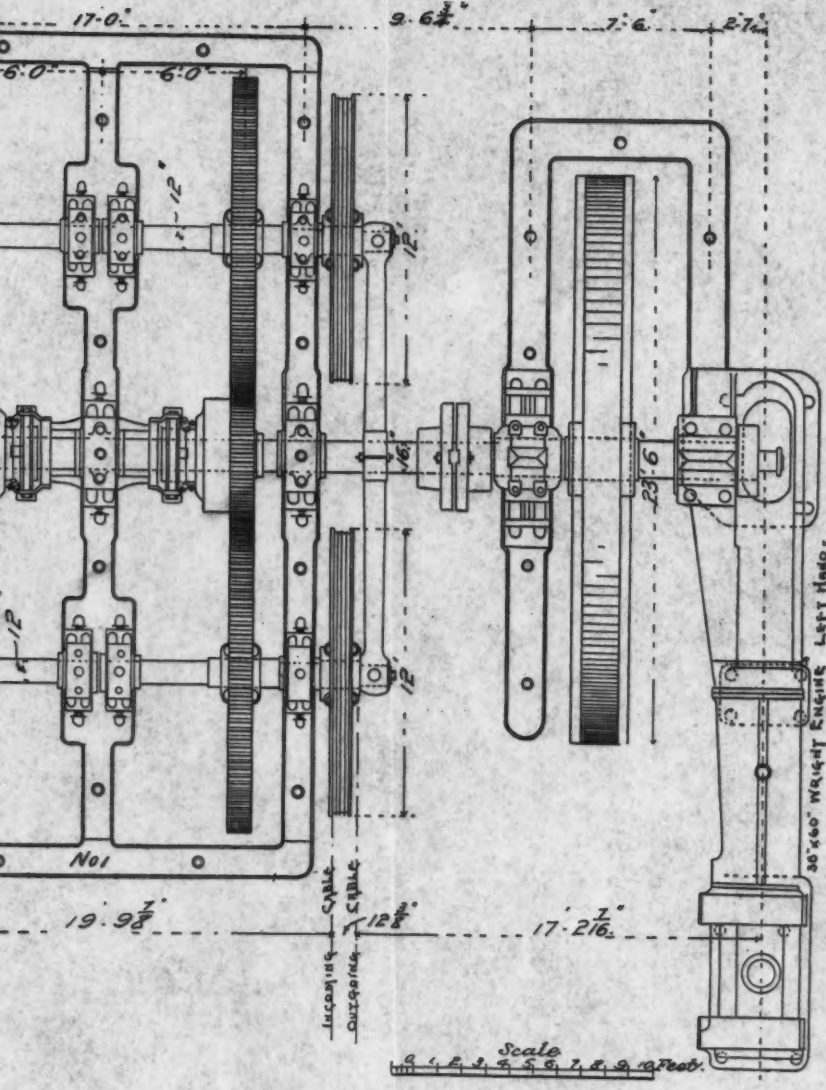
Soc. C.E.



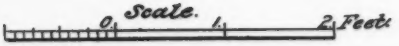
of Cleveland Cable Railways Machinery

W. H. PAINE AND
— ROBERT GILLHAM, MEM'S AM. SOC. C.E. —
ENGINEERS

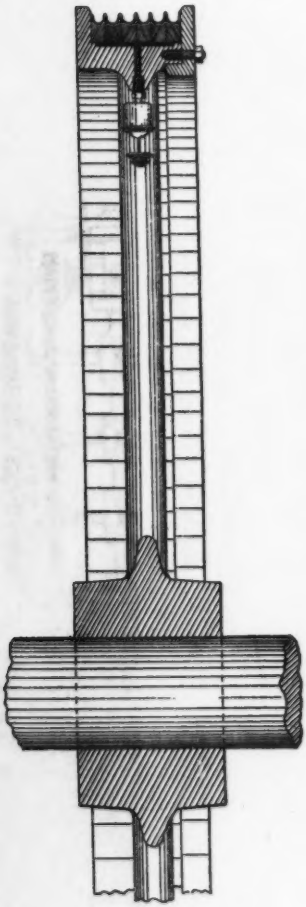
ARRANGEMENT


17-0"
9-6 3/4"
7-6"
2-7"
6-0"
6-0"
12"
12"
12"
12"
23-6"
No1
19-9 7/8"
12 3/8"
17-2 7/16"
CABLE
CABLE
35"x60" WRIGHT ENGINE LEFT HAND.
Scale
0 1 2 3 4 5 6 7 8 9 10 Feet.

SECTIONS OF WALKER DIFFERENTIAL AND SOLID DRIVING DRUMS.



WALKER



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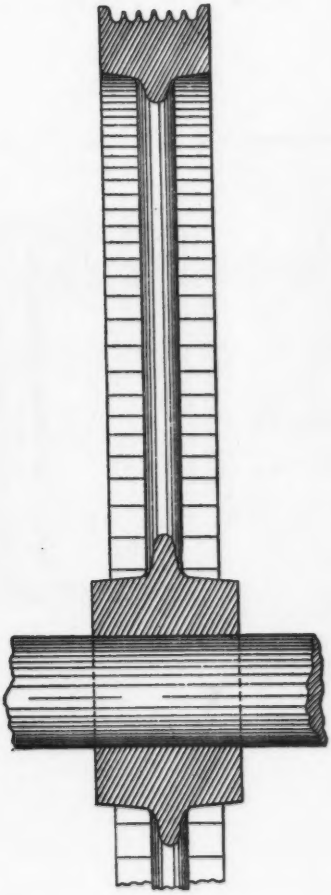
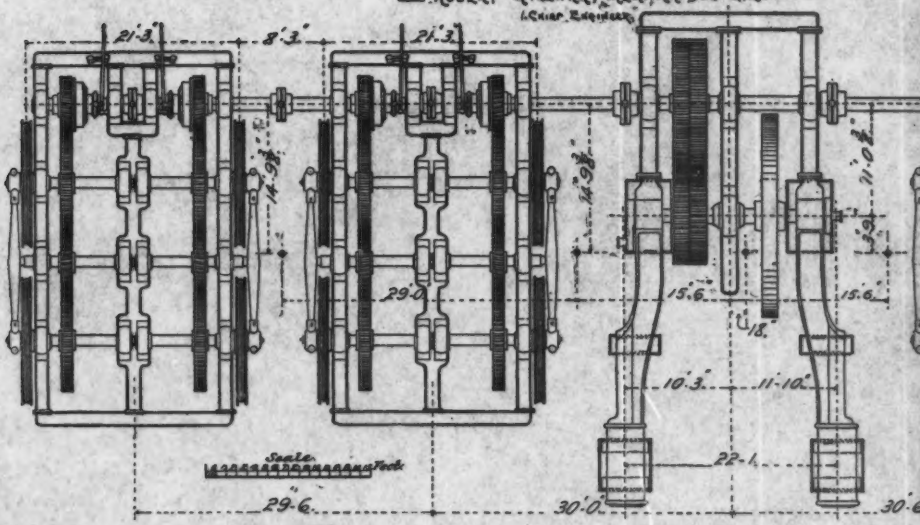


Plan of Denver City Cable Railway Machinery

ROBERT GILLHAM, M.E.M. Am. Soc. C.E.
Chief Engineer



VOL. XXIX, No. 623.
TRANS. AM. SOC. CIV. ENGRS.
GILLHAM ON CABLE RAILWAYS.
PLATE IV.

Cable Railway Machinery.

M. Mem. Am. Soc. C.E. —
Engineer.

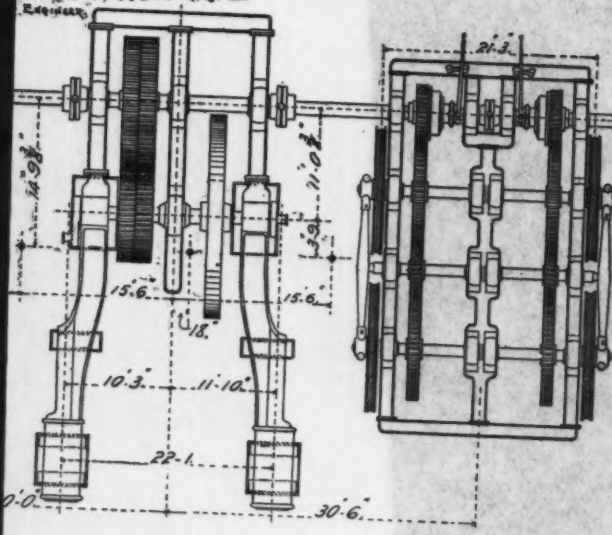


TABLE No. 14.

Denver City Cable Railway.

Location.	Length of cables tested.	Speed in miles per hour.	Horse-power per linear foot of cable.	Remarks.
	Feet.			
Larrimer Street.....	23 100	10	.00546	Conduit was not clean; much dirt in it.
Sloan's Lake.....	31 250	10	.00322	Three double-track cable crossings.
Seventeenth Street....	11 850	10	.00235	Two double-track cable crossings.
Welton Street.....	36 850	10	.00566	Three double-track curves; one double-track cable crossing.
Seventeenth Avenue...	25 297	10	.002932	One right-angle curve and one 60° curve.
North Denver.....	27 270	10	.002120	One 40° curve; one double-track cable crossing.

(Not including engine friction.)

TABLE No. 15.

Chicago City Railway.—(Fifty-fifth Street Station).

Location.	Length of cables tested.	Speed in miles per hour.	Horse-power per linear foot of cable.	Remarks
	Feet.			
No. 10.....	22 572	13.76		
No. 11.....	22 472	13.76	All cables considered .0064.	Individual cables not tested.
No. 12.....	10 868	13.76		
No. 13.....	3 786			

Twenty-first Street Station.

No. 1.....	20 302	9.65	....	Individual cables not tested.
No. 3.....	23 620	9.65	All cables considered .0065.	
No. 5.....	4 600	....	....	Auxiliary cables.
No. 6.....	4 700	....	....	Auxiliary cable.

The tests in this paper are submitted as the result of actual investigations relating to the transmission of power for cable railway operation.